METALLURGIA

The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER)

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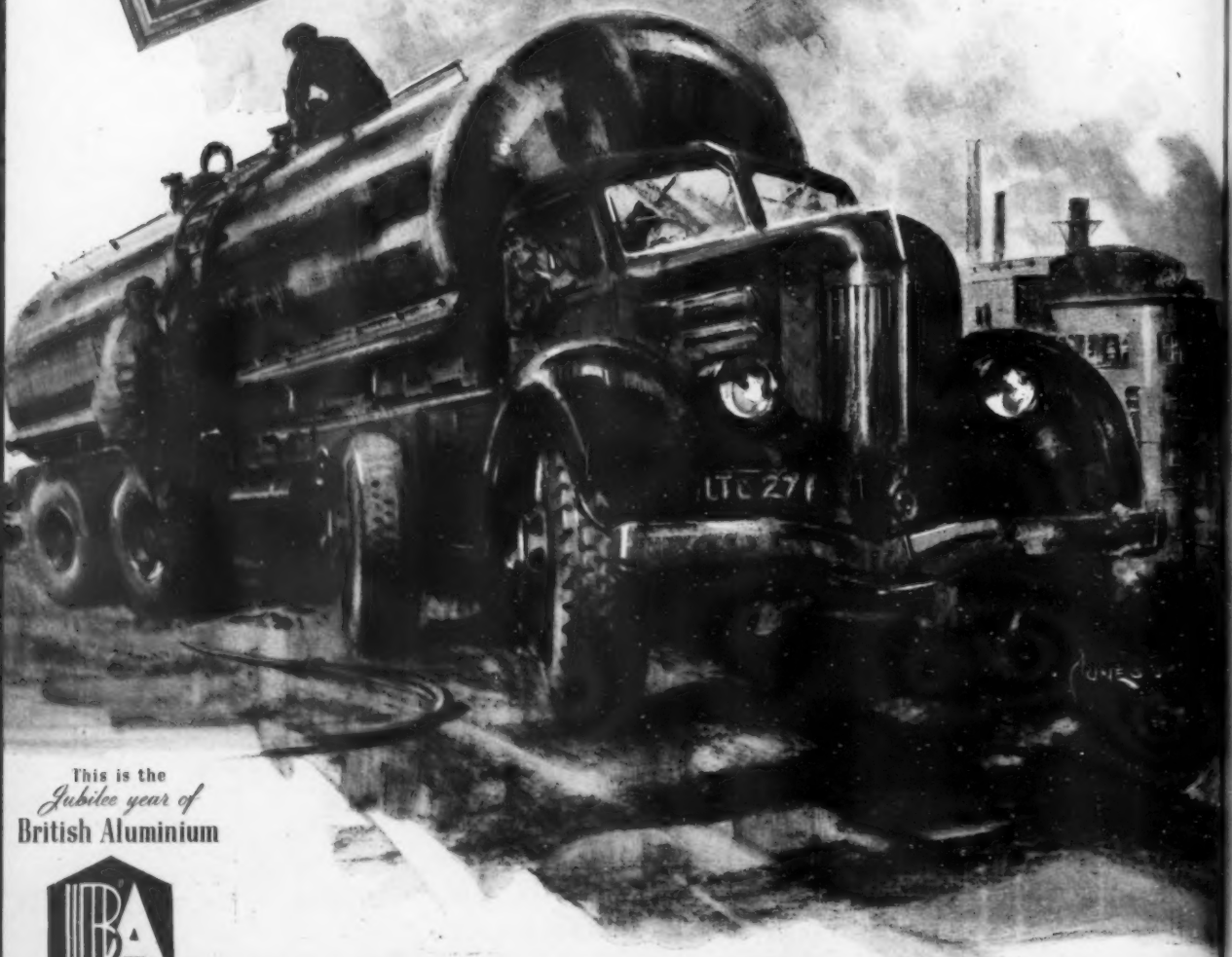

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METALLURGIA

THE BRITISH JOURNAL OF METALS.

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APRIL, 1945 VOL. XXXI. No. 186

Export Trade Research

WITH the conclusion of the war on Germany a question of weeks the need becomes increasingly apparent for an export plan. To facilitate her reconstruction Britain must import and, probably more than any other industrialised country, she cannot afford to lose sight of the fundamental principle that international trade is an exchange of goods and services for goods and service. Some time ago we stated that, on the defeat of Germany, international trade will present numerous problems and it was suggested that some form of international agreement and machinery must be devised to control it during the reconstruction period. However diffident one may feel in deciding on the maintenance of such control, because of the difficulties of agreement and the possibilities of delay and frustration, it was felt that such a course would be desirable. Certainly, a lead seemed necessary to assist export planning on a long-term basis and to remove anomalies that exist, because the institution of export control would obviously be of a temporary character.

A far-reaching plan to assist the revival and subsequest maintenance of Britain's export trade has been announced in a brochure published by an influential group of British industrialists. Briefly, the plan is that British industry should co-operatively establish its own organisation for conducting market research and maintaining a trade intelligence service throughout the world. For this purpose it is proposed to set up a British Export Trade Research Organisation with headquarters in London and branches in every overseas territory. Pending the formation of overseas branches, it is proposed to create in London a "flying-squad" of expert research personnel ready to go overseas at short notice to carry out market research in any given territory. The flying-squad will form the nucleus of the eventual world wide organisation.

The promoters of this project are some sixteen leading industrial companies (representing about £175 million of capital) and a number of advertising agencies experienced in market research work. They state that efficient production will by itself be of no avail if the goods produced for export cannot find a market. Many of our former markets have been permanently lost. Owing to the wartime development of local industries, competition will be keener than ever before and in some cases we shall be trying to establish or to re-establish trade relations with people whose living standards and preferences have been profoundly changed by the direct impact of war. We shall not only need to obtain a detailed and intimate knowledge of the markets of the world as they exist when hostilities have ceased, but also permanently maintain, supplement, refresh and improve upon our appreciation of world-wide trading conditions.

Those who view the subject of export superficially will regard trade with occupied and liberated countries as the most important aspect. The peoples of these countries need practically everything and the problem will not be to find markets but to send adequate supplies. It must be remembered, however, that as soon as these countries are again established their goods will be competitive with ours in many markets we shall be developing. For a permanent build-up of export trade particular attention must be directed to those countries not touched by the enemy and this plan for a wider and deeper knowledge of overseas marketing conditions can be regarded as essential and certainly a move in the right direction.

The final consumer or user of goods or machinery is still the final factor and it is necessary to penetrate far below the surface of a possible market to obtain the information, without which an intensive trade effort is not likely to be successful. Opinions on the subject are not reliable and have no practical value ; facts are needed objectively stated and statistically reliable, such as are obtained by market research. The idea is not new, a knowledge of general conditions in overseas markets has been built up through the British Consulates, the Department of Overseas Trade, Manufacturers' Associations, and similar organisations, but these are primarily concerned with the necessary ground-work. The changed conditions demand more intensive work to discover the detailed facts needed by manufacturers wishing to market their products overseas or desiring to know the particular products which can be successfully marketed.

Considerable attention has been given to the need for increased efficiency of production and numerous technical and trade associations are functioning with this object in view. In its broadest sense increased efficiency not only includes developments resulting from scientific and technical research and the use of the most modern plant and machinery, but also the human factors in industry. As soon as workers and managements unite in service with the common object of using the most up-to-date machinery available to reach the highest degree of efficiency, manufacturers will be in a better position to supply the demands of the community whether at home or overseas. In some cases the demand for supplies of British products already exists, but in others, particularly overseas, it must be increased and developed, and, rightly used, a really live export trade research association, such as is planned, should prove an invaluable asset to British industry, and it's formation will be welcomed.

The fact that goods made of raw materials in short supply owing to war conditions are advertised in "Metallurgia" should not be taken as an indication that they are necessarily available for export.

A Great Man Has Passed

JUST on going to press with this issue, the freedom loving world and the United States in particular were profoundly shocked at the passing of President Roosevelt. It is unfortunate that one who has contributed so much to the cause of freedom should have been called to rest when victory over oppression and slavery, for which he worked so hard, had almost been achieved. He was a great statesman and a great man, and history will record him among the outstanding personalities striving for the freedom of the common people.

We in Britain know that we had in him a loyal friend, who, in our darkest hour, had sufficient faith and confidence in us to stake the resources of his country in an effort to support and see us through. He saw clearly that we had not sought war but that the cause of freedom for all nations, great and small, was at stake. This was evident long before his country entered the war. Not only has he striven unceasingly to bring together the English speaking peoples, but his activities were towards a world fellowship, and to this end he seemed to be possessed of that spirit which moves mountains.

Whenever such men die it seems untimely, because it seems part of their quality that they radiate power and give strength to all with whom they come into contact and never cease to contribute to the well-being of mankind. Although he has now ceased active participation in solving the problems war has set, the principles for which he laboured so long and zealously will continue to give guidance to all peoples for generations to come.

The Aluminium Development Association

BRITISH elements in the aluminium alloy production and fabricating industry have formed a new development association. Its formation is timed to throw the full weight of the industry into the problems which must arise in the transition from war to peace. That every effort will be made to apply the seven-fold war expansion of this industry to peace time activities is indicated by the members of the first Council of this Association which comprises: The Hon. Geoffrey Cuncliffe, president; Mr. Horace W. Clarke, vice-president; Mr. D. C. Brookes; Mr. W. C. Devereux; Mr. H. E. Jackson; Mr. E. Player; Mr. Austin Reynolds; and Mr. G. A. Woodruffe.

The Association's main objective is to develop new and extended uses for aluminium alloys by initiating or assisting in the production of prototypes, encouraging research of all kinds, and by undertaking propaganda designed better to inform the public of the many uses to which this versatile metal should be put.

Membership is open to users of the metal, who should apply to the Association's Offices at Union Chambers, 63, Temple Row, Birmingham 2. Those familiar with the work of the Wrought Light Alloys Development Association will recognise this address and will note with satisfaction that this Association which has already done so much useful work will be absorbed at a later date within the more comprehensive body. For the greater convenience of those making use of the facilities to be offered it is intended to open Offices in London as soon as possible.

X-Ray Analysis in Industry

THE X-ray Analysis Group of the Institute of Physics held its 1945 Conference in London on April 12 and 13. The meetings were held in the Royal Institution, by kind permission of the Managers. The Conference was opened by Professor Sir Lawrence Bragg, O.B.E., F.R.S., the chairman of the Group. The time occupied by the Conference was increased over that in previous years, allowing the morning of the first day to be devoted to a number of short contributions on new and improved methods. In the afternoon there was a symposium on the Equipment of X-ray Laboratories, at which papers were read by Dr. R. F. Hanstock, Mr. H. S. Peiser and Dr. W. A. Wooster. Dr. Hanstock, of High Duty Alloys, Ltd., dwelt specially on equipment for determining residual stresses in metals. Mr. Peiser, of Imperial Chemical Industries, described a number of types of X-ray apparatus of wide applicability, and Dr. Wooster, of the Department of Mineralogy and Petrology at Cambridge University, described chiefly the accessory crystallographic equipment that is necessary in addition to the X-ray apparatus.

Iron and Steel Institute

THE Annual General Meeting of the above Institute will be held at the Institution of Civil Engineers on May 9 and 10, 1945, at which the Institute of British Foundrymen has been invited to take part. The meeting, over which the President, Mr. Arthur Dorman, will preside, is more comprehensive than during recent years. In addition to the official business the Bessemer Gold Medal will be presented to Mr. Harold Wright and the Williams Prize to Mr. G. D. Elliot and the following papers will be discussed at the various technical sessions:

(1) The Application of Radiography to the Improvement of Foundry Technique." By R. JACKSON. (Paper No. 13/1945 of the Steel Castings Research Committee.)

(2) 'First Report of the Foundry Practice Sub-Committee." (Paper No. 12/1945 of the Steel Castings Research Committee.)

(3) "The Influence of Centrifugal Casting upon the Structure and Properties of Steel." By L. NORTHCOTT and D. MCLEAN.

(4) "Examination of Two Ingots of Free-Cutting Steel, One containing Lead and the Other Lead-Free." By C. S. GRAHAM. (Paper No. 31/1945 of the Committee on the Heterogeneity of Steel Ingots.)

"The Microscopical Examination of Samples of Lead-Bearing and Lead-Free Steels and Ingot Irons." By T. H. SCHOFIELD. (Paper No. 32/1945 of the Committee on the Heterogeneity of Steel Ingots.)

"Mode of Occurrence of Lead in Lead-Bearing Steels and the Mechanism of the Exudation Test." By W. E. BARDGETT and R. E. LISMER. (Paper No. 33/1945 of the Committee on the Heterogeneity of Steel Ingots.)

(5) "The Constitution of Basic Steel Furnace Slags." By J. R. RAIT and H. J. GOLDSCHMIDT.

"The Phosphorus Reaction in Basic Open-Hearth Practice." By Y. K. ZEA.

"A Study of the Basic Open-Hearth Process, with Particular Reference to Slag Constitution." By A. H. JAY.

There will be a luncheon for members at the Connaught Rooms, Great Queen Street, London, W.C. 2, on May 10, at 1 p.m. Owing to limited accommodation the number of guests must be restricted to two per member, and applications for luncheon tickets (price 15s. per head) cannot be considered after April 30.

Keltic Metal Work and Manuscript Illumination

By Douglas Rennie Hudson, B.Sc., Ph.D.

Lecturer in Metallurgy, Heriot-Watt College, Edinburgh.

"Hibernian Art at its best was, even in matters profane, essentially a monastic phenomenon."
A. MAHR, 1941.

"That the Irish system of ornamentation does actually find an analogy in Eastern countries is proved by the illustrations published by C. Knight in a small work on Egypt. We find there the serpentine bands of the Irish ornaments appearing already in the oldest Egyptian and Ethiopian manuscripts and with a similarity of colour and combination truly astonishing."
F. KELLER.

ABSTRACT.

From critical assessment it appears that the Keltic Style developed from Continental La Tène; the whorls, trumpets and scrolls may be correlated with Aegean patterns. Irish penannular brooches may be traced back to Halstatt and eventually to spectacle *fibulae* from the Balkans. Following St. Patrick's evangel, sublimation led to a vigorous mission throughout Europe, from Iceland to Italy. Foundation of famous monastic workshops led to a magnificent *floruit* about the 9th century, but the christianization of Bavaria and Switzerland by the Keltic Mission is better known. Red enamel, probably introduced about A.D. 200 from Wales, where yellow and blue also flourished, became characteristic of Irish monastic work. Designs in manuscript illumination, which led the world, are shown to be derived from the intricate patterns of metal interlacing, and the author suggests that decoration in red dots (to the exclusion of other colours) is a copy of the orange-red spots in Irish *cloisonné*. Early *Scotic* metal tradition, which stood so high while Europe sank back into barbarity during the dark ages (400–1000), profoundly influenced Occidental craftsmanship for a millennium, not only in metal work but in the derived art of manuscript ornamentation, right down to the invention of printing from moveable types. In the zoomorphic designs of hideous distorted lizards and birds the Keltic is modified by strong Teutonic influence.

1. DEVELOPMENT OF THE KELTIC STYLE

FINE examples of Keltic ornaments have been recovered from many countries in Europe—Ireland (Fig. 3, 6, 7, 8), Gaul, Scandinavia (Fig. 1), Germany (Figs. 9, 10), Wales, Scotland (Fig. 2). In its early stages metal working was distinguished by a pattern of three or four commas, with tails developing into scrolls, and resembling Japanese Tomoyé and Buddhist designs. The Keltic style existing in the British islands before the Roman conquest, was an import from the Rhineland where it had evolved under Mediterranean influence. Local development, which has been called "late Keltic," is characterised by bold conception, fine enamelling, and first-rate metal work in interlacing spiral and trumpet patterns, reaching a zenith in the area of the new Belgic occupation. In Britain, red, blue and yellow enamels had attained great perfection when they suddenly disappeared about A.D. 200. Red (or orange) enamel is often regarded as characteristically Irish, and it is true that it occurs widely on Hibernian metal jewellery for many centuries. So much so, that it has been used as an indicator of Irish monastic workmanship in the abbey shops of southern Europe. It is quite certain that Roman occupation dealt a heavy blow to native art in Britain and SMITH has suggested that the red-orange was introduced by fugitive craftsmen from Wales, where Imperial control was only superficial. On the other hand KILBRIDE-JONES would prefer an importation into Ulster in the 2nd century A.D. from Scotland, which

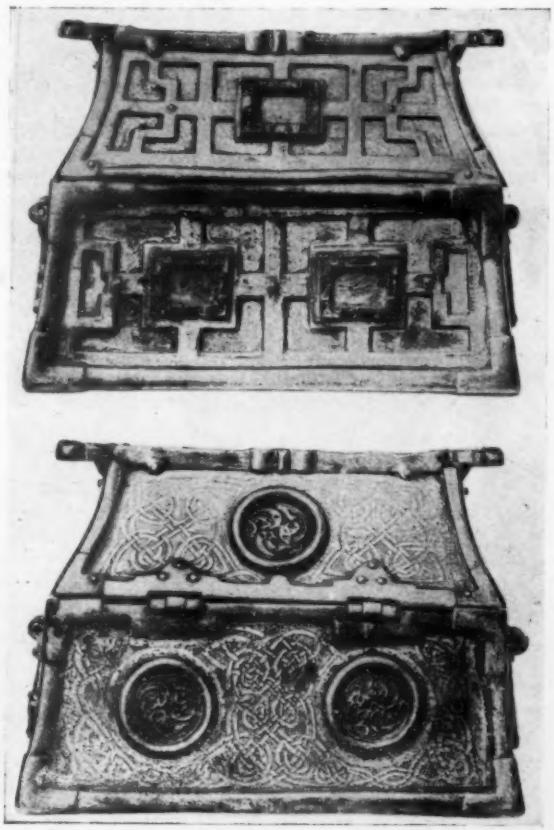


Fig. 1.—Reliquary of Keltic type found in Norway, possibly Viking loot from Ireland. On the bottom is a runic inscription: Ranuaik a kistu thosa —"Ranvaig owns this box." Compare with Fig. 2, 8th century A.D. National Museet Köbenhavn.

never came under Roman authority, perhaps this took place via Galloway and Man. Apart from the discrepancy of 1–2 centuries, which seems to be real but may not be serious, there is a more fundamental difficulty in this diffusion from Britain: While the red enamel was widely and enthusiastically adopted in the Irish monasteries, the yellow and blue did not come into use till the 8th century A.D., although they flourished in Britain contemporaneously with red. A scarcity of necessary minerals would, of course, explain the anomaly; this is possible, if unlikely. Before further light can be shed, a combined study of the material, available in such profuseness, will be required, by an expert on primitive jewellery, in conjunction with a chemist, expert on enamels. As it is inconceivable that any *cloisonné* workmanship should be damaged, chemical investigation, even micro-analysis, seems ruled out. X-radiology might yield some useful information though too much cannot be expected. Examination by a skilled microscopist would be worth undertaking especially from the point of refractive index. These two techniques would, of course, have no deleterious effect on the jewels under examination.

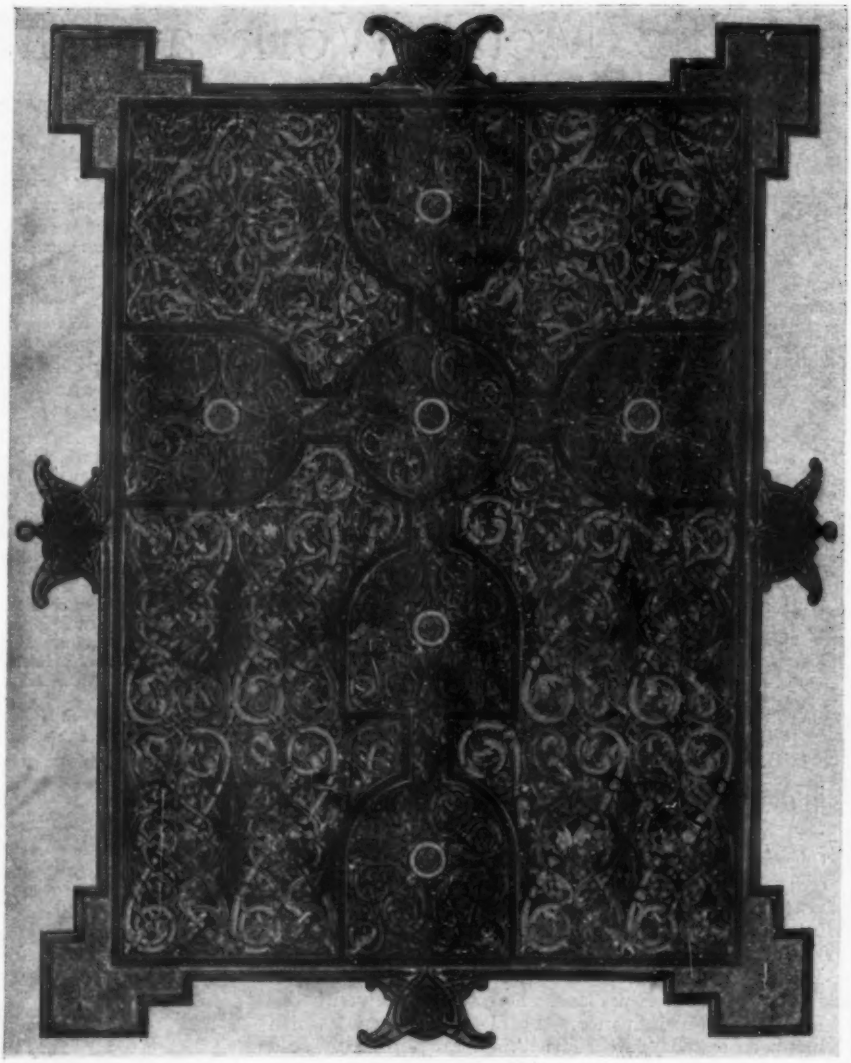


Fig. 4.—Finest of four cruciform pages from the Lindisfarne Gospels. Compare with the "Irish" metal cover of the Linden Evangelary, Fig. 9. In its whole conception, in treatment and colouring, this manuscript design obviously derives from metal-working tradition. Circa A.D. 700

Fig. 2.—The Monymusk Reliquary, front view. (About ⅔ actual size.)

"Late Keltic" and Continental la Tène

Indigenous Keltic metal craftsmanship, existing before the Roman conquest and of central European origin, can be correlated with the analogous *la Tène* style of the continent. Probably this was domesticated in north England and Scotland and did not reach Ireland till a comparatively late date, about 200 B.C. Stone engravings from Man would support the thesis that this island was a stepping stone. Certainly a remarkable homogeneity persisted in the two portions of this area, separated by 20 miles of

Fig. 5.—Illumination of St. Matthew's Gospel, Chap. i, Verse 18. INCIPIT EVANGELIUM SECUNDUM MATTHEUM. Particular veneration was attached to this in the Keltic Church—XPI (CHRISTI) AUTEM GENERATIO SIC ERAT CUM ESSET DESPONSATA MATER EIUS MARIA IOSEPH . . . Note decoration with red dots, analogous with red spots in cloisonné enamelling, and the gloss in Old Northumbrian. Zoomorphic and spiral patterns glow in their balance of colour, doubtless the outline letters were intended for subsequent gold leaf burnishing.

North Channel, right down to the 8th century A.D. The high competence and the *Wanderlust* of the monastic Hibernian jeweller helped to preserve this unity; compare, for example, illumination in St. Chad's and Lindisfarne Gospels (A.D. 700 ?) with the Book of Kells, and the metal work of the Cross of Cong.

"SCOTIC" METAL CRAFT

In view of the distribution of this Keltic style, many archaeologists use the name *Scotic*. RAFTERY's comment on the *Brecbannoch*, of great sentimental veneration as having belonged to the founder of Christianity in Scotland, is expressed with a charm so typically Irish. "The Monymusk reliquary is the only one of its kind ever found in Scotland, and the fact that St. Columba came from Donegal and that his church always upheld the connections with the church in Ireland undoubtedly lends support to a view which forces itself upon us from purely stylistic considerations: namely, that the object, in spite of the many centuries it had been in Scotland is fundamentally an Irish one, or to put it in other words, that it belongs to a time at which it would have been difficult to distinguish between Irish and Scottish art styles." In the 6th and 7th centuries A.D. Irish monks penetrated deeply into the monasteries of Scotland and Northumbria. Their art flourished till the abject surrender of the Synod of Whitby to the Roman Pope on doctrinal and

Fig. 3.—The famous "Tara Brooch," found in 1850 near the mouth of the River Boyne, probably part of a Viking hood. This bronze jewel is partly gilt, chased with first-rate scroll work and decorated with gold filigree. It is set with amber and blue and purple pastes and the back is decorated with red and dark blue enamelling. This, with the Quoniam page from the Book of Kells, represents the summit of Irish artistic achievement. Circa A.D. 700. National Museum of Ireland.

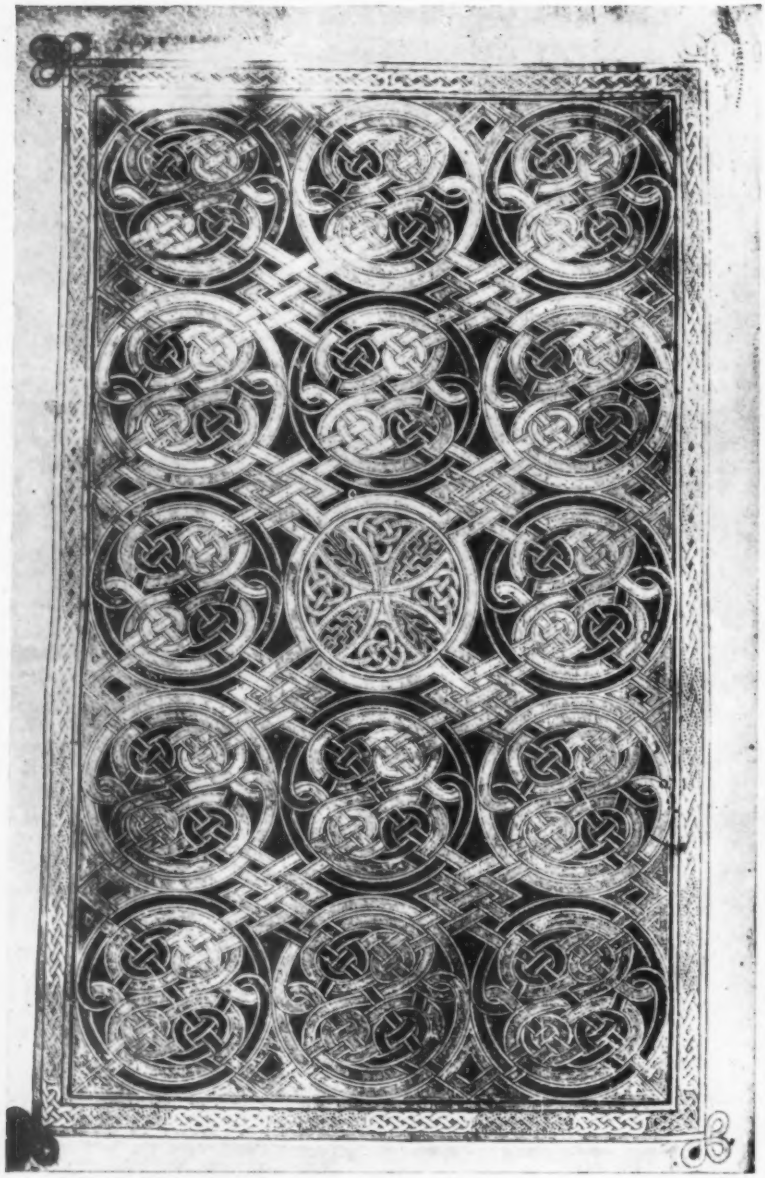


Fig. 6.—Manuscript page facing St. Mark's Gospel in the Book of Durrow. 7th century A.D. Note resemblance to relief metal work. Trinity College, Dublin.

ritual points in 664 A.D., after which these prototypes of the *Original Seceders* went out into the wilderness, and their fine heritage vanished.

On the whole, Roman influence had pernicious effect on jewellery in Britain, but it did cause the native craftsmen to give greater attention to execution and embellishment of detail. With the departure of the Imperial power, something like a mild revival occurred of which the *Mabinogion* are evidence, unfortunately the effect was neither deep nor very lasting. It is possible, therefore, that native tradition was more persistent than would appear on the surface, although we cannot produce any direct evidence. It is in Ireland, which never came under Roman rule or influence, that we must seek our relics of metal culture, and here we are amazed by the richness of the heritage which remains.

Irish Ecclesiastical Art

Of the multitude of fine Hibernian objects that remain to us, it is at first sight astonishing that so many are ecclesiastical—reliquaries of "book" and "house" type, episcopal crooks and T-crosses reminiscent of the Greek Orthodox ritual, shrines of many types, of bells, of St. Patrick's and St. Lachtin's Arm, and even of St. Brigid's slipper! One cannot but regret the lack of lay objects, apart from the numerous and exquisitely worked brooches (Fig. 3), from which notable conclusions have been drawn by typological analysis. Household goods are rare and pottery is entirely absent.

Brooches.—The penannular brooch is generally considered a typically Irish production, up to the 12th century A.D. Its development can be traced back through Roman modifications to the hoop fibule of continental *la Tène*, and eventually to Hallstatt culture and spectacle fibulae of the Balkans. Continental *la Tène* seems to have been established in Ulster about the second century B.C. Modified by a strong Teutonic component of intertwined fantastic beasts and birds (Salin style) it formed the basis of the Keltic style which later developed so splendidly, free from Roman influence and undisturbed by internal dissensions, under vigorous leadership of the tall fair aquiline-nosed Gaels or Goidels. (See Fig. 3).

Influence of Christianity.—The evangel of St. Patrick (A.D. 389–461) gave sudden and forceful impetus to Keltic art by sublimation of creative activity to religion. Hibernian missionaries penetrated to Scotland, Northumbria, Iceland and Wales, St. Columba (Colum Cille) founding his settlement on Hy or Iona in 563, this is regarded as the prototype of the Kirk. The vigour did not quickly abate and *Scotic* art reached its acme in the seventh century; an astonishingly high standard being maintained for centuries. Further, this "Christian" renaissence was carried far and wide by itinerant Irish monks; excellent examples are the 9th century cover of the Lindau gospels manufactured in South Germany (Fig. 9), and the conversion of Switzerland and Bavaria by the *Iro-Schottisches, Missions Kirche.*

Mission Centres. Well-known centres of Irish influence are Bobio in Piedmont and Luxeuil in France (A.D. 590) founded by Columbanus, and St. Gall in Switzerland named after the founder. ". . . the great Irish mission in the 6th and 7th centuries resulted in external relations which opened to the Irish artist the store house of the whole of European and Byzantine art. At the same time it is a remarkable fact that the foreign elements were so completely absorbed in the Hibernian style as to look almost like an organic growth."—MAHR.

THE CHRISTIAN KELTIC STYLE

As a result of the wealth of artefacts available, it has been possible to divide the "Christian Keltic" style into four periods.

1. *Vernacular Keltic.* A.D. 700–850. Towards the end, *la Tène* patterns were displaced by interlacement.
2. *Hiberno-Viking.* A.D. 850–1,000. During this time the island was constantly harried by intermittent raids from Scandinavia, and as a result many treasures of this period are to-day found in northern museums. It came to an end with the Vikings' *débâcle* at Clontarf in 1014.
3. *Later animal style.* A.D. 1000–1250. With the Mammen and Urnes styles which gradually developed in Scandinavia, a distinct divergence from Hibernian art can be traced.

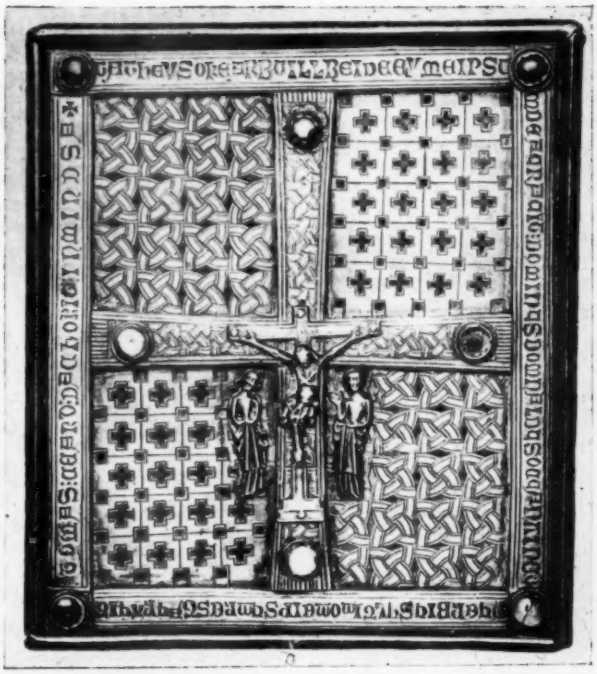


Fig. 8.—Shrine of Dimma's Gospels (back) silver and bronze. Hiberno-Romanesque Style, 12th century A.D.; compare with the Shrine of St. Patrick's Bell (Fig. 15). It is clearly composite work. The front is older, resembling the Scotic cover of the Lindau Gospels and probably re-fashioned from an original metal "cumhdach"; its inscription in copperplate reads: "The inclosed copy of the Four Gospels was written by Dimma the son of Nathi who died about A.D. 620" Half scale. National Museum of Ireland.

Fig 7.—The Ardagh Chalice, found in 1868 near Limerick. The chased gilt bronze bowl is attached to the silver foot by an iron tang. The construction is intricate, employing brass, lead, silver and enamel, set with pastes, amber, Cairngorms and mica. Probably 9th century A.D. Height, 7 in. National Museum of Ireland.

4. *Hiberno-Romanesque.* A.D. 1250—Norman Occupation. With the subjection of the Keltic Christian Church to Canterbury, native art, hitherto so vigorous and splendid, flickered and died out. Craftsmanship never recovered from this blow.

By the 11th and 12th centuries, *champlevé* had practically displaced *cloisonné.*

Who will deny the splendid contribution to metalcraft made by the early Keltic church, never very tolerant of Roman pretensions? All the more surprising, this occurred while the rest of Europe sank into degradation in the fluctuating strife between barons, states, kings, and villeins.

2. DERIVATION OF MANUSCRIPT ILLUMINATION FROM METAL CRAFT

Like metal work, Irish manuscript craftsmanship reached its summit about the 8th century A.D. The Book of Durrow may be allocated to A.D. 650–700, the Lindisfarne gospels about A.D. 700, the Book of Kells about A.D. 850 though there is some divergence of opinion. Analogies between Keltic metal work and illumination are evident at mere scrutiny. Compare, for example, the Tara brooch (Fig. 3) and initial capitulation in the Book of Kells; the similarity between the older (9th century) cover of the Lindau Gospels (Fig. 9) and the illuminated fly leaves of the Lindisfarne Gospels (Fig. 4). Metal work is the older and more permanent art, and it seems well established that the illumination patterns are derivative. Though this conclusion has

been questioned—a common origin like wattle can be postulated—there seems little doubt of its correctness. It is hard to conceive anything more unsuited to the flowing lines of the pen, or the bold sweep of the brush, or anything better suited to bench work in ductile gold and silver, than the involved interlacing pattern of a Keltic manuscript cross (Fig. 12 and 13). On the other hand, the same patterns in stone, a material even more refractory, are probably still older. To illustrate this derivation we consider four typical Keltic manuscripts.

LINDISFARNE GOSPELS

ZIMMERMANN has called attention to the analogy between cruciform flyleaves in the Lindisfarne manuscript and the older cover of the Lindau evangelary. BROWN would go even further, deriving them directly from metal designs; the circular ornaments in the centre of the spatulate portions (Fig. 4) being equivalent to rivets in the original metal work. Certainly the thesis is very plausible; looking at the figure without prior knowledge that it was a manuscript illumination, one might well think it was metalwork in relief. It seems quite inconceivable that this effect could be unintentional.

In execution, the Lindisfarne gospels resemble the magnificent Book of Kells, but there are definite differences on close examination. It is less overloaded with hideous animal (zoomorphic) ornament, brighter in colouring and contains fewer decorated pages. The *Motiv* of the scheme is made up of dogs and cormorants with interlaced necks, balanced in design and colours with the utmost care. Typically Keltic decoration with red dots is richer and more profuse than in any other text which we possess (Fig. 5). One most ingenious and effective design is the formation of a cruciform interval at the intersection of four knots, as may be seen in the bottom right-hand corner of Fig. 4.

Fig. 9.—Older cover of the Lindau Gospels. The original Scotic work, including the involved zoomorphic convolutions, dates from circa 800 A.D. The many repairs—e.g., corner pieces and chased right-hand marginal gold strip, extend down to 16th century.

Materials.—Principal LAURIE of this College, the distinguished authority on artists' materials, in 1914 found the pigments to be *red lead*, *malachite*, *orpiment* and *ochre* for yellow, badly washed *ultramarine*, purple from *purpura lapillus* a mollusc found on the coasts of Britain and analogous with the Tyrian colour, and possibly *sepia*. *Gold leaf* was used very sparingly and laid on without burnishing. It was not possible to say whether the gum was gum arabic or a native like cherry gum.

Decoration.—The *Scotic* decoration rivals even that of Kells. "A regular programme seems to have been drawn up beforehand, by which the perfect balance of design and colouring was ensured even in the most complicated patterns, while at the same time variations were introduced to prevent any of the work becoming mechanical and the artist has with a few exceptions adhered to his self-made rules with a fidelity and a clear-headedness that are little short of miraculous"—MILLAR. But we must not allow our enthusiasm for these fine designs—admittedly near perfection—to induce us to take up an attitude of *The Elephant and the Rights*

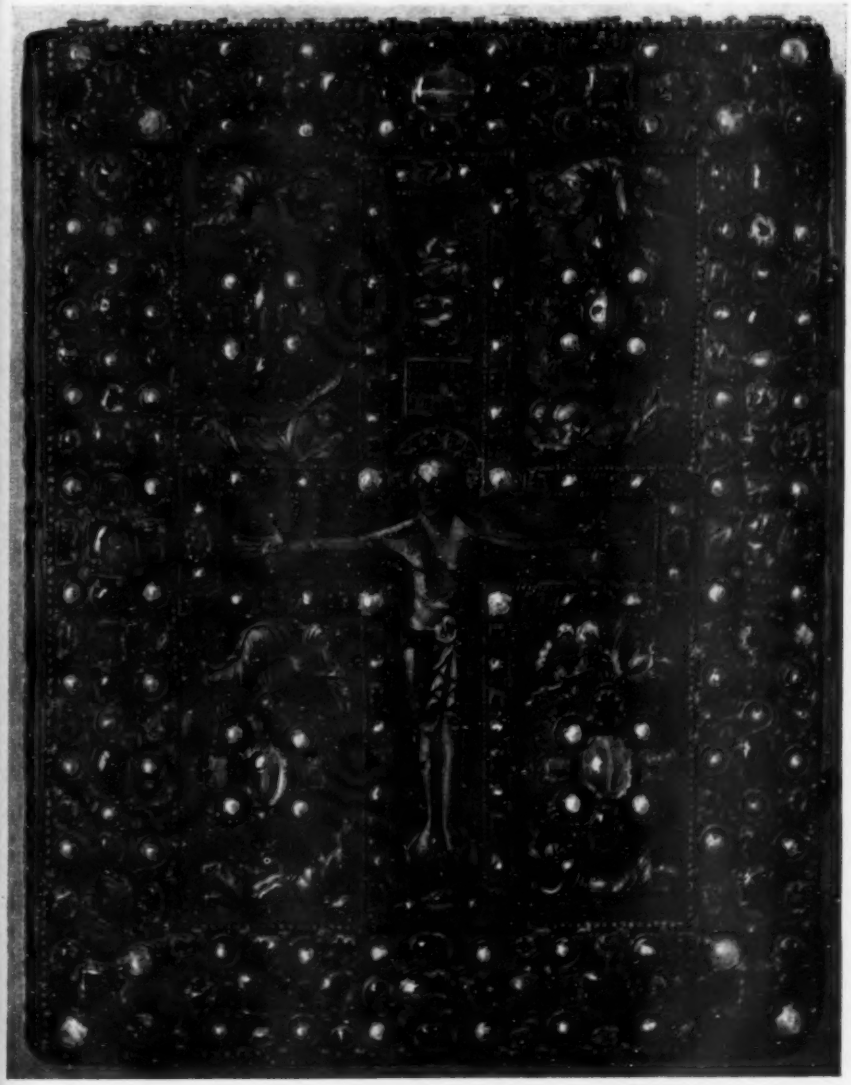


Fig. 10.—Newer jewelled metal cover of the Lindau Gospels, 9th century, probably re-made from an earlier jewelled artefact. Apart from replacement of gems, few alterations have been made. Estimated to be the finest Carlovingian jewel in existence.

of Poland. Decoration is almost purely geometrical, the artist was wholly ignorant of perspective, and much less able to draw the human figure than his brother in Egypt two millennia earlier. The whorls, trumpets and scrolls of Keltic geometrical ornament have been plausibly compared with spinal patterns on the pottery of the Cyclades, Mykenæ and Crete, *circa* 1500 B.C. (Fig. 11).

Manuscript.—The Latin text in insular half-uncial script follows closely the Codex Amiatinus now at Florence, and is regarded as an important source for the Vulgate. Possibly both were copied from an Italian original in Northumberland. After the Synod of Whitby, co-operation within the Christian Church improved greatly, Bishop Benedict the ardent collector made altogether five journeys to Rome, bringing back books and pictures on each occasion. These were nuclei of the fine libraries at the monasteries of Wearmouth and Jarrow (Abbot Ceolfrid), which he founded.

A running interlinear gloss which greatly spoils the appearance, was added after about two and a half centuries probably by Aldred. This Northumbrian *patois* is of greatest palæographic interest as the earliest translation of the gospels into "English." His colophon reads :—

> . . . *Eadfrid* biscop lindisfearnensis æcclesiæ *he ðis boc avrat aet frvma gode sce cvðberhte, allvm daem halgum gimaenelice ða ðe in eolonde sind* . . .
> . . . *Eadfrith, Bishop of Lindisfarne Church, wrote this book, at first, in honour of God and Saint Cuthbert, and all saints in common that are on this island* . . .

Two art styles can be traced, Keltic and Italian (East Christian). In contrast, the southern English school showed definite Byzantine influence ; the famous Gospels of Utrecht belong to the Winchester-Canterbury group, with a peak about A.D. 950.

The Lost Jewelled Cover.—Originally it was housed in a *capsa* like the Lindau Gospels, but of this no trace remains. Crossing to Ireland as a refuge from Viking invaders in 875 the bishops lost the sacred objects overboard in a storm in Solway. However, next day a miraculously low tide occurred "and after walking three miles or more they recover the holy codex of the Gospels itself, showing all its outer glory of gems and gold, and the original intrinsic beauty of letters and pages, as if it had never been touched by water" *ac si ab aqua nimine tactus fuisset*. It is certainly in an excellent state of preservation to-day, but if the account be true it is quite possible that more than one sacred manuscript existed—"any self-respecting codex of the time would lose caste if it did not tumble into the water and emerge triumphant."—Brown. No enterprising astronomer has looked for a special conjunction of the moon at that date to account for the miracle ! The manuscript was written " . . . in honour of the blessed Cuthbert, and the venerable Æthelwald, his successor, who caused it to be adorned with gold and gems, and also

of St. Billfrith the anchorite (*anachoritae*) who, obeying the instructions of his superior, with his own hand composed a magnificent work. For he was outstanding in the art of the goldsmith."

ST. CHAD'S GOSPELS

In Lichfield Cathedral Library the Gospels of St. Chad, probably of Welsh origin, show definite Irish (i.e., *Scotic*) characteristics. They were obtained by one Gheli in exchange for a fine horse, and presented by him to Llandaff Cathedral about the end of the 8th century. By the episcopate of Wynsige (A.D. 974–992) they appeared at Lichfield.

The manuscript is sadly damaged by damp. Colours are less brilliant and less varied than in Lindisfarne, but this may be due to deterioration at least in part. Green does not occur and it may be earlier than the A.D. 700 generally assigned.

THE BOOK OF COLUM CILLE (ST. COLUMBA)

The best known Keltic manuscript in the world is undoubtedly the Gospels of Kells. Its name derives from the famous monastery, the founding of which is attributed, somewhat shakily, to St. Columba in A.D. 550 at Kennansa, latinized to Cenondae, and later corrupted to Cennanus and Kenlis. No trace of it remains, but finely engraved stone crosses exist.

Manuscript.—The manuscript consists of 339 leaves of finely glazed thick parchment in half-uncial and some half-cursive script, in different hands. Due to carelessness of a bookbinder some of the decorations have been cut, and on one blank leaf the signatures of Queen Victoria, her husband, and her son, have been inscribed ! The text is mixed, some of the deviations from the Vulgate are of interest to theologians. This Latin Version of St. Jerome was laid down by the Roman power in the sixth century, pre-Augustinian Keltic Churches continued to adhere to the Old Italic (Pre-Hierominian) down to the ninth century ; hence the different readings.

Several chapters, estimated at 24 leaves, are wanting and most regrettably there is no *colophon*. Possibly these were removed at the same time as the jewelled gold *capsa* in 1006, when according to the *Annals of Ulster* it was stolen by night and recovered only after two months, hidden under sods.

Decoration.—The book has been much used, as shown by its rubbed pages. Decoration is rich in spiral interlacements, distorted animals *and plants*. Geometrical patterns closely resemble those of St. Chad and Lindisfarne especially the cruciform page ; of these, other three may be wanting. The design is obviously far advanced beyond the primitive and pleasing decoration of Durrow (Fig. 6), admittedly one of the earliest Irish books. Man, and a variety of animal forms, some hideously grotesque, are depicted, e.g., the dog or lion, an otter carrying a fish in its mouth, rats apparently gnawing communion bread, while watched by cats . . . " amongst the immigrant races that had established themselves in the land before the introduction of Christianity the worship of the serpent was practised, though perhaps not very widely. It is even possible that this was the serpent which St. Patrick is said to have driven out of the country."—SULLIVAN. This would explain the recurrent reptile pattern. Illumination of the Eusebian carons is particularly good. As in Lindisfarne, St. Chad, and Durrow, the full page decorations are reminiscent of metal work, and a comparison can be drawn between decorations of initial letters to the chapters and cloisonné work in Irish crosses. Before 450 there were probably no manuscripts in Ireland. St. Columba is said to have left over 300, *in his own hand.*

Materials.—HARTLEY in 1885 found the pigments to be lamp black or possibly fish-bone black, scarlet *realgar*—i.e., arsenic sulphide, yellow *orpiment, malachite,* deep blue possibly *lapis lazuli,* reddish purple either a glass coloured with gold or a *purple of Cassius.* The latter colour was used very sparingly, and metallic gold is not found. Pigments were laid on thickly, in a gum, glue, or gelatine medium. The black is remarkably well preserved and remains very dense, it contains no iron.

Dating.—We have no historical facts regarding the age of the book. A strong tradition attributes it to the personal use of St. Columba, but this seems very doubtful. There is great variation in the dates which authorities ascribe to the book—6th–9th century. In view of the finished nature of the illumination patterns, the introduction of plants and a variety of animal forms, the firmness of the penmanship, the types of contractions, and the horrific distortions of the zoomorphic ornaments, the author would not allocate it to a date earlier than the middle of the 9th century. This great work seems to show all the features of sublime artistic attainment at the zenith which immediately precedes decadence. In Irish church metal work, of which happily there are so many examples, the process can be observed quite distinctly. Comparison with other manuscripts of known age would be of great interest, though owing to diffusion of craftsmen's styles and techniques it might not be quite conclusive with the few examples that we can date with certainty.

In *Topographia Hibernia,* the historian *Giraldus Cambrensis* in the 12th century described a fine illuminated manuscript which he saw at Kildare. Many commentators have accepted it as Kells, and indeed there is little inconsistent with this in his details. But no mention is made of the lost jewelled cover, and with other doubtful points the author prefers to think that the Welshman described an earlier manuscript, perhaps copied from the same source. For instance, the fine " monogram " page f. 34R, at the eighteenth verse of the first chapter of St. Matthew's Gospel, which is regarded as the epitome of Keltic illumination, shows analogies with the same pattern in St. Chad's Gospels and the Lindisfarne book (Fig. 5). In the latter this χ PI (*Christi*), and the *Quoniam* beginning St. Luke's Gospel show close resemblance to corresponding words in the Echternach Gospels in Paris *lat.* 9389, in folios 19*a* and 116*a*, though here treatment is much simpler. However, the beginning of St. Matthew's Gospel *Liber Generationem,* folio 29*a* in Kells, shows only distant analogies with the same page in Lindisfarne and St. Chad. (*To be continued*)

Erratum

On page 229 of March issue the name "C. E. Daniel," at bottom of right hand column, should read C. E. Davies, as many readers will know.

Emulsions of Oil in Water as Corrosion Inhibitors

By P. Hamer, L. Powell and E. W. Colbeck

Research Department, Imperial Chemical Industries Ltd.

This paper describes an investigation which was undertaken with the object of preventing corrosion in recirculating cooling systems, and which was begun as a result of plant failures. Attention has been chiefly directed to the prevention of attack on mild steel. Three types of water have been used under both static and flow conditions at room temperature, and at 60° and 90° C. Extracts from this work are given here together with the author's conclusions.*

As a result of the rapid failure of high-pressure mild steel coolers in recirculating cooling-water systems, an investigation was undertaken in a search for inhibitors which might be suitable for large systems of this kind. The failure tubes had a wall thickness 0·1 in. and a bore of 0·3 in.; the cooling water passed over the outside of the tube, and failures occurred in a few months as a result of severe pitting.

At the suggestion of Dr. U. R. Evans, the authors of the work described in this report undertook a study of the behaviour and efficiency of oil emulsions made by the addition of "soluble oils" to water. The fact that these emulsions can act as corrosion inhibitors, particularly with respect to corrosion fatigue, has been recorded by a number of workers, but the authors were unable to find in the literature that any study of their behaviour as general inhibitors had been made.

The corrosion problem in a recirculating cooling system, and consequently the choice of a suitable inhibitor, is complicated by changes which occur in the water as a result of the operating conditions. In order to give some idea of the conditions under which a corrosion inhibitor will be expected to be effective, a list is given below of the most important factors which must be taken into account.

(1) The volumes of water in circulation may be as high as 2,000 cu. m. per hr. with a make up of about 10% of this volume. The cost of the inhibitor is therefore important.

(2) Concentration of salts in the circulating water occurs as a result of loss by evaporation. There are also losses of water by spray, which tend to limit the concentration of salts, but which will remove inhibitor at the same time. Concentration is also sometimes limited by a small purge.

(3) Temperatures may be as high as 70° or 80° C.

(4) As a result of the concentration of salts and the rise in temperature, sludges and scales of calcium carbonate may be found on the metal surface and in other parts of the plant. These are derived from the temporary hardness of the water, even when this hardness is low in the make-up water, as is the case with most moorland surface supplies.

(5) The temperature and other conditions favour the growth of bacterial and vegetable slimes on the metal, and these, in conjunction with the other deposits, prevent free access of inhibitor to the metal surface, and may thus encourage pitting in place of general attack or complete inhibition.

(6) The pH value of the circulating water usually rises; owing to the loss of CO_2, but in certain circumstances it may fall, owing to the absorption of acid gases from the atmosphere.

(7) Non-ferrous metals are usually present in some part of the plant—e.g., circulating pumps, or may have to be used because of the nature of the substances to be cooled.

The problem can be simplified to some extent by treating the make-up water to remove the temporary hardness and by intermittent chlorination to prevent slime growth. In the authors' view such steps are justifiable on the grounds of the economies to be secured through improved heat transfer and reduction in cleaning costs; also because they simplify the task of the corrosion inhibitor. The best time at which to take these measures is obviously when the plant is first put into commission.

With these considerations in mind the authors tried to devise their experiments to cover the conditions of temperature, water flow and water composition in recirculating cooling-water systems. It speedily became evident, however, that an enormous number of experiments would be required to make a complete study of the variables involved, and, in practice, the authors have fallen far short of their programme. The results and conclusions given in this paper must therefore be regarded as a general survey of the field. The conclusions are based on some six hundred experiments, of which only a few typical cases are recorded in the paper, but the evidence presented is sufficiently convincing to demand the attention which this type of inhibitor deserves.

Experimental Method

The main idea throughout the investigation has been to find the amounts of inhibitor which will stop corrosion. No attempt was made, therefore, at any detailed study of comparative rates of corrosion in the presence of different amounts of inhibitor.

It was considered that a state of complete inhibition existed when the specimens, after treatment, showed no general attack or pitting judged by inspection and/or negligible weight loss.

The difficulty of reproducing corrosion effects at will (e.g., pitting), even under the most carefully controlled experimental conditions is a matter of common experience and this consideration must be taken into account when devising methods of investigation. A preferred method is to carry out simple types of experiment, in triplicate or quadruplicate, under a variety of conditions, so that the general trend of events can be determined with reasonable confidence.

* Iron and Steel Inst., Feb. 1945. Advanced copy. 20 pp.

This method was followed as far as possible, taking into account the large number of experiments envisaged, and all important observations were made in duplicate—i.e., two separate experiments, sometimes with two or three specimens in each experiment. Where two or three similar specimens were submitted to the same environment at the same time, the total loss of weight of all specimens weighed together was divided by the total area. The usual time of exposure was one week, but longer periods were allowed in some cases.

In the flow experiments compressed air was used to circulate the water. It was found that a specimen suspended in the aerated column suffered greater loss in weight than the specimen in the liquid column. These results are not included in the figures given because such conditions may be regarded as abnormal; nevertheless, the point is of interest.

Variables Studied

The following variables were taken into consideration:

(1) *Condition of Liquid Medium.*—Static and flow.

(2) *Temperature.*—Room temperature 60° and 90° C., alternate heating to 60° C. and cooling to room temperature.

(3) *Condition of Metal Surface.*—No. 1 emery cloth and/or smooth filed finish; some experiments with mill-scaled and pre-rusted specimens.

(4) *Metals Employed.*—Mild steel, aluminium, copper brass (60:40 and 70:30), cast iron. Bi-metal specimens: Aluminium/steel, copper/steel, brass/steel, aluminium-bronze/steel, manganese-bronze/steel, cupro-nickel/steel and copper/cast-iron.

(5) *Character of Waters.*—Three types of water were used in the first experiments, but when it had been established that the behaviour of the inhibitor in all three was much the same only the most accessible source of supply was used. For brevity, the results obtained with modified river water only are tabulated in the paper.

The waters were typical samples of their class, and were modified by adding suitable salts to give the kind of composition which might be expected from the concentration of waters of these types in a recirculating cooling system. Only the modified waters were used.

Oil Emulsions

The oil used was a proprietary product sold as an anti-corrosion emulsifying or soluble oil. It is clear reddish-brown in colour and consists essentially of a mixture of mineral oil, the sodium salt of a sulphonated mineral oil and a small amount of water. It forms a stable milky emulsion quite readily when added to water with stirring, particularly when the water is warm.

No careful study of the properties of the emulsions was made, but some observations obtained during the experimental work are recorded. For instance, the authors state that when the soluble oil is added to water it forms a surface layer of oil, but this is rapidly emulsified on stirring by hand. Some soluble oils emulsify much more readily than others. No data regarding particle size are available, but it is probable that emulsions made up in this way at different times differ to some extent in stability and particle size, so that for any future series of experiments it may be advisable to adopt some form of standard stirring or to employ a colloid mill in preparing the emulsions. When made up by hand the emulsions often tend to separate a layer of oil on standing for periods of one week or more, but this does not happen if they are kept stirred. They can be evaporated down to half bulk without separation.

A more satisfactory method of making up emulsions is to pipette the required quantity of oil into a small portion of the water to be used, warmed to a temperature of 50–60° C., shake vigorously to emulsify and add to the remainder of the water.

With hard waters a scum forms slowly, and this is no doubt due to the formation of calcium and magnesium soaps from the hardness salts and the emulsifying agent. With soft water, as might be expected, there is considerable foaming, but no scum. Both of these phenomena might be objectionable in full-scale plant. There is evidence that the addition of substances such as "Calgon" or tannins, which are known to form soluble complexes with calcium and magnesium ions, can reduce the scum, but further experiments are necessary.

It was found on several occasions that the emulsions, particularly those of low concentration, broke down during corrosion experiments; this breakdown is attributable to three factors:

(1) The removal of emulsifying agent as scum, followed by absorption of oil by the scum, or conversion of the emulsion into a water-in-oil type.

(2) Adsorption of oil and emulsifier by surfaces of glass or metal, or by insoluble corrosion products.

(3) Coagulation of emulsion by small amounts of metallic ions.

Further work is needed to establish the conditions under which dilute emulsions can be kept stable, since these are the least costly to use. The risk of breakdown of emulsions in contact with metals appears to be less if there has been a preliminary treatment with a more concentrated emulsion.

Conclusion

The investigation was limited to an attempt to answer certain questions which appeared to be of practical value and the work described in the paper has enabled the authors to arrive at the following conclusions:

(1) Oil emulsions can be effective inhibitors of the corrosion of mild steel in natural waters of widely differing types, at temperatures up to 90° C., under both static and flow conditions.

(2) Metal surfaces which have been exposed to oil emulsions retain their passivity in untreated water for a limited time. Satisfactory protection can be obtained by pretreatment with a heavy dose followed by subsequent continuous application of a much lighter dose.

(3) Non-ferrous metals alone or in contact with mild steel are protected by oil emulsions both under static and flow conditions at room temperature. At 60° and 90° C., however, local attack takes place on both steel and cast iron in contact with non-ferrous metals.

(4) With mild steel or non-ferrous metals it is of primary importance to maintain a stable emulsion, since breakdown may be accompanied by pitting. Attention must also be drawn to the intense corrosion which occurs at 90° C. at points which may be relatively inaccessible to the oil.

(5) The progress of corrosion is definitely retarded and possibly stopped when oil emulsion is in contact with metal surfaces on which the corrosion products are still present. The most efficient protection is obtained, however, when the metal surfaces are clean, and under these conditions less oil is likely to be needed to maintain a stable emulsion.

(6) With clean metal surfaces exposed to oil emulsion the heat transfer is only slightly affected, but it should be borne in mind that, if untreated water is used, a much greater fall in heat-transfer rate will rapidly occur as a result of the formation of rust. The use of oil emulsion in previously corroded tubes the heat-transfer coefficient for a short time compared with that obtained with natural water alone. There is, however, a subsequent decrease in the efficiency of heat transfer.

(7) Evidence is presented which appears to show that the inhibiting properties of the oil emulsion may be due to the formation of a thin film of oil on the metal surface, with thickening at specially susceptible anodic points.

(8) Any treatment of cooling water for the prevention of corrosion must take into account the formation of scales and slimes. The full effect of these on the prevention of corrosion by oil emulsions or other inhibitors has yet to be investigated. It appears advisable to remove scale- and slime-forming constituents from the water before use in cooling systems.

(9) The results given in this paper must be regarded as a preliminary survey of the subject, but, in the authors' opinion, sufficient evidence has been accumulated to show that the soluble mineral oil used is worthy of consideration for trials in full-scale plant.

(10) While the effects of a light-grade mineral-oil emulsion have been considered herewith, it might be useful to extend the study to vegetable and animal oils. It might also be an advantage to have a more viscous film for high-temperature work, but the authors were not successful in forming stable emulsions with heavy lubricating oils, and time did not permit a further study of these aspects.

The authors acknowledge their indebtedness to Dr. U. R. Evans for his help and encouragement.

A Photo-induction Defectoscope

A method of detecting defects in metals by means of photo-electric measurements is described by Professor M. M. Sliozberg, of the Siberian Institute of Metallurgy, and whilst details of specific applications of the instruments described are not dealt with, the author has presented a novel and relatively simple testing method which appears worthy of further study.*

THE magnetic field caused by the presence of a defect in a metal under the influence of the induction system of a defectoscope cannot in any noticeable manner have a direct effect on a photo-element. The very valuable properties, especially the high sensitivity, of photo-elements have been applied, however, to the defectoscope by the author by making use of a principle described previously by him.† Essentially this consists in transforming alternating current into light and then back again into electric current, in the form of photo-current. The measuring apparatus is called "a photo-transformer of currents."

A diagrammatical scheme of photo-electric measurement of alternating current is shown in Fig. 1, where the alternating current, $\sim I$, which is to be measured, produces by means of a variable transformer, T_p, a definite glow of the photometric lamp filament, L. Rays from the lanp are directed through the optical system on to the photoelement, ϕ_3 (a selenium cell with enclosed element). Through the galvanometer, g, there passes a direct current, $I\lambda$, which is responsive to quite weak changes in the alternating current, $\sim I$.

Under these conditions, just as in the case of an optical pyrometer with disappearing filament, the relationship between the intensity of filament radiation, $E\lambda$, and the temperature is given by Planck's equation:

$$E\lambda = C_1 \lambda^{-5} \frac{1}{e^{\frac{C_2}{\lambda T}} - 1},$$

where C_1 and C_2 are constants, λ is the wave-length and T is the absolute temperature. The great value of the proposed method of measuring temperature and thereby alternating current is due to the fact that $E\lambda$ increases rapidly with rise in temperature. (With a temperature increase of 1,000°K. to 2,000°K. the radiation intensity, for rays of wave-length, $\lambda = 0{\cdot}65\mu$, is multiplied 60,200 times.) Thus, when the current which is causing the lamp. filament to glow is increased only slightly, an enormous increase occurs in the intensity of radiation and, correspondingly, in the magnitude of the photo-current. Experimental data, set out in Table 1 serve to demonstrate the exponential character of the variation of the direct current, I_G, in the galvanometer, with changes in the alternating current, U~. The unresolved light of a 4-volt torch lamp, a photo-element with a light-sensitive surface of 20 sq. cms. and a sensitivity of 420 milliamps. per lumen and a galvanometer with a sensitivity of $0{\cdot}25 \times 10^{-6}$ amps. per 1° were used in these experiments. The scale of the galvanometer comprised 100 divisions. The values in the table in excess of 100 were found by calculation from the coefficients of the galvanometer shunt.

TABLE I.

$I_G = f(U\sim)$

U~ (volts)	I_G (reading)	U~	I_G	U~	I_G	U~	I_G
1·0	5·3	1·8	125	2·6	580	3·4	1250
1·1	9·5	1·9	160	2·7	670	3·5	1665
1·2	16·0	2·0	205	2·8	765	3·6	1815
1·3	24·0	2·1	253	2·9	865	3·7	1970
1·4	36·0	2·2	312	3·0	980	3·8	2130
1·5	51·5	2·3	375	3·1	1110	3·9	2310
1·6	69·5	2·4	442	3·2	1245	4·0	2510
1·7	96·0	2·5	510	3·3	1380	4·1	2730

The diagram of a photo-electric defectoscope, given in Fig. 2 differs from that of Fig. 1 in that it includes a source of electric current (2–4 volts), B, which provides a basic glow of the lamp when the E.M.F., which is induced by the magnetic field, is insufficient. Before the application of the defect detector, the induction coil, to the article to be tested, it is desirable that the

* *Zavodskaya Laboratoriya*, vol. 10, 1941, pp. 279–281.

† "Electro-optical method of measuring alternating current and voltage by means of photo-elements" M. M. Sliozberg, *J. Tech. Phys.* (U.S.S.R.), 1937, 18–19.

galvanometer needle be brought to zero. For this purpose a potentiometer, P, is included in a compensating circuit to neutralise the current in the photo-cell circuit. By the use of the compensation system it is possible to reduce considerably the effect on the coil of the general magnetic background which forms around the rough uneven surface of the article being tested.

A system possessing greater accuracy and sensitivity is outlined in Fig. 3. By means of this scheme it is possible to suppress the errors which may arise on account of the magnetic background and the characteristics of

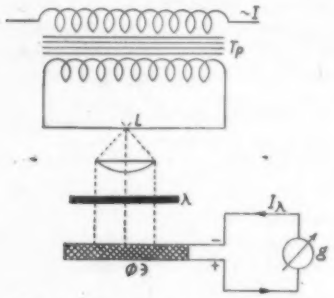


Fig. 1.—Photo-electric measurement of alternating current.

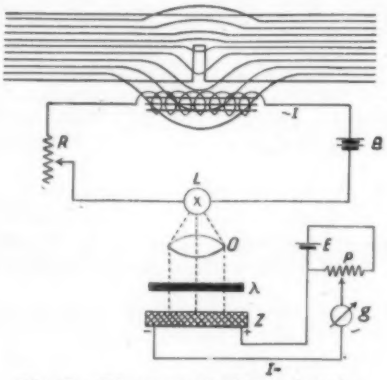


Fig. 2.—Diagram of photo-electric defectoscope.

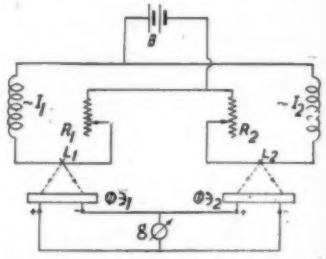


Fig. 3.—Differential photo-electric defectoscope.

1_1—induction coil, placed over defective part.

1_2—induction coil, placed over sound part.

the current which is employed for magnetising the article (variations of voltage in the mains) and also on account of the propensities of the photo-element itself. The differential scheme which is indicated includes two identical parts. One contains an induction coil for application to a sound part of the article and acts as a standard and the other contains a coil for the detection of defects. The selenium photo-elements are short-circuited through the galvanometer to increase the sensitivity. Still greater accuracy may be obtained by employing the author's logometric method of photo-electrical measurement.‡ The two photo-elements and the two lamps of the scheme of Fig. 3 are fitted into a case having external dimensions, 150 × 60 × 80 mm.

From a consideration of the maximum permissible loads of the photometric lamps, induction coils, connected with each lamp in series, are selected with a small ohmic resistance of the order of 2–3 ohms.

The curves in Fig. 4 illustrate the way in which a change in the direct current through the galvanometer is dependent upon a change in the alternating current, for a sound and a defective part of a rail. The separation between the curves, which is indicative of a defect, depends both upon the current used in magnetising the rail and the supplementary potential on the lamp, $-U_B$. It is significant that an alteration in the voltage from 0·4 volts (U_{B1}) to 0·42 volts (U_{B2}), i.e., 0·02 volt, produces a considerable shift in the curves. Bearing in mind that the supplementary voltages used were insufficient to raise the lamp filaments to full incandescence, the author points out that very great reserves in respect of sensitivity remained untapped. The defect which was detected by the apparatus, was a zone of non-metallic inclusions, devoid of pearlite, running 3 mm. into the interior of the rail from the base.

The stability of the photo-electric defectoscope was confirmed in further experiments. A current of the same strength, I_L, is passed through the two lamps, connected in series. By means of shunts with resistances, R_1 and R_2, which are connected with their respective galvanometers, the photo-currents indicated are brought to the same value, a_1 or a_2, whichever is the greater.

When the current strength is lowered the two independent photo-currents are nearly equivalent over the whole scale of the galvanometer. The coincidence is particularly marked for normal and sub-normal filament incandescence and somewhat less with a weak glow.

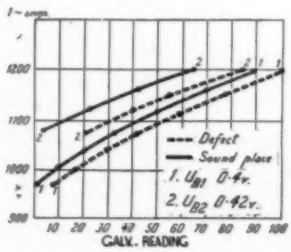


Fig. 4.—Graphs showing variation of the reading of the galvanometer of the photo-electric defectoscope with the strength of the alternating current for a a sound and defective portion.

TABLE II.

Relationship between the readings of the galvanometers, a_1, and a_2, and the current through the lamps.

GALVANOMETERS.
No. 1.—Resistance, 335 ohms; Scale, 1°=0·25×10⁻⁶ amps.
No. 2.—Resistance, 830 ohms; Scale, 1°=0·26×10⁻⁶ amps.

Lamp current, / x (milliamps)	Galv. readings		Shunt resistances (ohms)	
	a_1	a_2	R_1	R_2
200	96·0	96·0W		
190	65·0	65·0W		
180	47·0	46·5W		
170	28·0	27·3W	51	84
160	17·0	16·0W		
148	8·0	7·0W		
140	5·0	4·0W		
218	98·2	98·2W		
213	86·5	86·5W		
200	58·5	58·0W		
195	47·0	46·0W	29	44
163	12·0	11·0W		
152	7·0	6·0W		
240	95·0	95·0W		
230	79·5	79·5W		
223	66·5	66·5W		
215	53·5	53·0W		
200	34·5	33·5W	17	24
190	24·0	23·0W		
180	17·0	16·0W		
170	10·0	9·0W		
160	6·5	5·5W		

Experimental results are given in Table II. Thus the

‡ *J. Tech. Phys.*, 1937, **22**.

ratio, equal to unity, of the two photo-currents corresponds with the ratio of the currents passing through the lamps, a ratio fixed at the beginning of the experiments by means of the shunt rheostats. It is remarkable that this constancy is maintained in view of the fact that the apparatus is of a primitive nature, e.g., the lamps are not photometric lamps but pocket torch lamps and there is no proper optical system apart from the tiny tinplate reflectors. For the detection of defects it is, of course, the relative and not the absolute values of the induced currents in respect of sound and faulty places that are important.

Patent Extensions and Foreign Profits

By S. T. Madeley

IT is a well established precedent that in Applications for extensions of Patent Term under Sub-Section 6 of Section 18 of the Patent Acts, full disclosures must be made of any profits arising out of corresponding foreign patents. It will be remembered that under this sub-section application may be made on the sole ground of loss or damage due to hostilities.

In demanding a full disclosure of profits on foreign patents and connected matters, the Court has in mind that whatever loss may have been incurred by the patentee in the development of his British patent may have been recovered by the profits he may have made on his corresponding patents abroad. Obviously, the bearing which foreign legislation may have on a disclosure of the kind referred to is of the utmost importance. A case has now been decided in which this is the leading feature, and a summary thereof follows hereafter.

The Kantzow patent No. 298408 was filed in the United Kingdom by H. G. Avon Kantzow, and Aktiebolaget Kanthal, a Swedish company, and claimed the Swedish Convention date.

It relates to fire resistant alloys with high electric resistance and is directed towards an alloy containing essentially 0·5–14% aluminium. The cobalt or cobalt and titanium content is up to 6%. Up to 12% of manganese or up to 30% of chromium or both may be added. Iron forms the balance. No manufacture of the patented alloys took place in this country. By an agreement made in May, 1942, Hall and Pickles Ltd. became exclusive selling agents and were authorised to sell the alloys in Great Britain, Northern Ireland and the Irish Free State. They bought the goods from Kanthal and also received stocks on consignment from the Swedish company, to be paid for within twelve months of delivery or return. In this country sales were as follows: 1936, 11 tons; 1937, 18 tons; 1938, 19 tons; 1939, 12 tons; 1940, 5 tons; 1941, 2 tons; 1942, 6 cwt.; 1943, nothing.

Kanthal granted a manufacturing licence in 1936 to Dentoche Edelstahlewerke A.-G. Manufacture under this this licence was but little and had ceased at the time of the hearing. Although the U.S.A. Government in 1941 started negotiations for U.S. manufacturing rights, they eventually terminated the negotiations.

Increased profits had been made by Kanthal during the war. Markets had been lost in the Allied countries, but had been retained in Bulgaria, Germany, Turkey and other countries. In 1941 and 1942, the Swedish Inland Revenue Board set aside assessments for war taxes, on the grounds that the increased profits were not due to the war. In 1943 the company was not so assessed. Swedish war-time legislation prevented Kanthal from giving information regarding sales of the patented alloys in different countries.

It was contended on behalf of the patentees that evidence that the company did not make increased profits owing to the war was afforded by the non-liability of the company to Swedish war-profits taxation, the "Conjunctive Taxes." The Court was asked to accept as sufficient the evidence of the Swedish Revenue Authority and, furthermore, was invited to extend the British patent beyond the term of the Swedish patent, which had already expired, both having expired at the time of the hearing.

In cases where there was manufacture in this country and manufacture abroad, the Court was of the opinion that manufacturers here might, in the case of grant of extension, be at a great disadvantage relative to those abroad where the patent had expired. It was suggested that an extension was unnecessary, as it would not affect manufacture here, but merely serve to control prices and prevent a free market in the patented product. However, it was pointed out that although there was no manufacture in this country, no application had been made under Section 27 of the Patent Acts for a compulsory licence or revocation of the patent on the ground of abuse of monopoly rights.

The Court eventually held that the sale of the patented article was substantially interfered with by the outbreak and continuance of the war, but was not satisfied that the patentees had not made a countervailing profit to offset the loss on the British patent. Despite the explanation brought forward that the applicant company was prohibited by Swedish law from supplying relevant particulars, the Court was not satisfied and insisted that it must be told all the relevant facts. The Judge said that if an applicant is the subject of a foreign state and is precluded by his municipal law from giving the necessary information to the Court that is his misfortune.

The Court next dealt with the exploitation of the patent in the United Kingdom through exclusive selling agents and with the manufacture of the material in Sweden when the corresponding patent had expired. Exploitation of the above kind was not, in the opinion of the Court, necessarily fatal to an application under Section 18 (6). Expiry of foreign patents, however, might be a great "obstacle" to the extension.

In the case of any monopoly public interest and provision of proper reward for the inventor must be balanced against each other. Although an extension under 18 (6) might be regarded as a substitutional term "it may have quite a different effect upon the public interest if the original term would be, but the new term could not be co-terminus with foreign patents. This may particularly be the case where the patent has been developed and manufactured abroad and has in this country been exploited only by a selling agency."

An extension was refused by the Court, mainly because of the lack, through no fault of the applicants, of essential information regarding profits.

Indentation Hardness

An Outline of a Physical Interpretation based directly on Stress-Strain Relationships

By G. C. Richer

Consultant on Research and Development, John Lysaght, Ltd.

If, as Helmholtz once said, the disgrace of the nineteenth century was its ignorance of the subject of magnetism, it must surely be one of the outstanding (but let us hope vanishing) disgraces of the twentieth that we still lack a proper understanding of the results obtained from some of the oldest and most familiar methods in daily engineering use in the "testing of materials"; and that, in particular, we cannot yet say what a "hardness" test really means.

The present writer happens to be interested both in the magnetisation and in the plastic deformation of ferromagnetic sheet material; and especially in the many thought-provoking linkages that exist between them. He has recorded elsewhere his conviction that "where ferromagnetics are concerned, investigations of plastic and magnetic phenomena can usefully be regarded as closely interwoven, and that they should very largely go hand in hand." [1] *It was, in fact, in the course of studying the provocative relationships between the two groups of phenomena that the ideas here outlined were conceived; and they are now presented in not too formal a fashion, but rather as an exercise in thinking aloud, in the hope that they may stimulate discussion and experiment which will ultimately make it impossible for some future Helmholtz to be too scathing about our own times.*

IT is now generally agreed that the true stress-strain relationships during the mechanical deformation of metallic crystalline aggregates can be diagrammatically pictured as in Fig. 1, in which Stage A represents almost wholly elastic and reversible processes, Stage C represents almost wholly plastic and irreversible processes, and Stage B represents a mixture of these two fundamental types of process, with the irreversible plastic type rapidly tending to predominate at the expense of diminishing elastic and reversible contributions.

The effects of different degrees of cold-work on an "annealed" diagram of this kind are shown in Fig. 2, which is based on experimental data recently published by MacGregor.[2] Fig. 2 reveals a number of extremely interesting points that are normally obscured by the more familiar modes of presentation of similar data. It will be seen

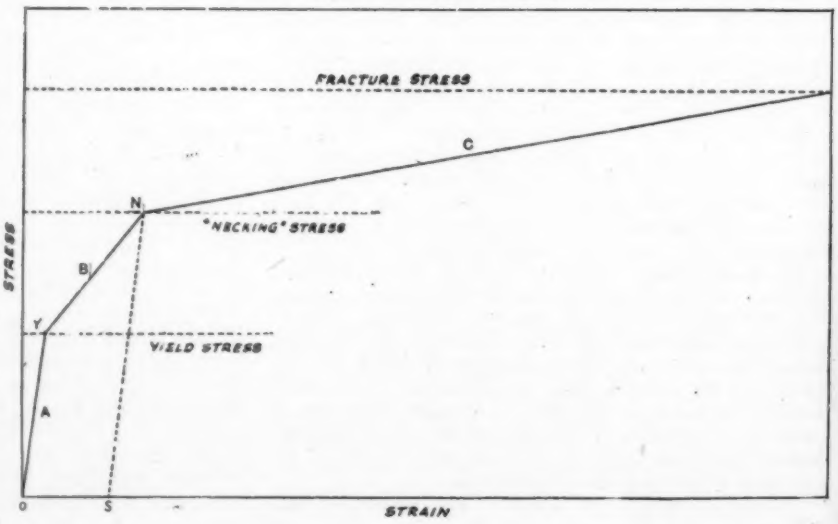
(*a*) that it is possible to draw a smooth curve NN′ through the observed "maximum load" or "necking" points;

(*b*) that it is also possible, by superimposing the subsidiary axes NR and RN′, to transform this curve NN′ into something that strikingly resembles a typical "Rockwell hardness v. cold-reduction" curve,[3] (the axis NR representing the hardness value for the "as annealed" condition); and

(*c*) that the horizontal intercepts between the curve NN′ and the stress-axis could thus be regarded as yielding a closely approximate measure of the relative depths of penetration of the Rockwell indenter for different initial conditions of the test specimen.

Fig. 2 therefore appears to indicate that the observed depth of indenter penetration is directly related to the strain-value shown by a given specimen at the point on its stress-strain curve beyond which *elastic* processes of deformation cease to exert any appreciable influence—i.e., at the end-point N of Stage B in Fig. 1 (the "necking" point); and this observation, coupled with the better-known but still "mysterious ratio" between

Fig. 1.—Idealised stress-strain relationships. Stage A—elastic. Stage B—mixed elastic and plastic stage plastic.



1 Richer. *Journal of the Iron and Steel Institute*, 1944, September (Advance Copy).

2 MacGregor. *Journal of the Franklin Institute*, 1944, September, (Tables IX-X, pp. 163-4).

3 O'Neill. "The Hardness of Metals and its Measurement." (Chapman and Hall). 1934, p. 119.

Brinell number and "tensile strength," seems to justify the conclusion that under the standardised conditions of a ball-indentation test, Stage C of Fig. 1 will not come into the picture.

But how can it come about, as it apparently does, that a strain-value recorded during a tension test can be the factor which determines the "arrest point" of an indentation hardness test, in which the effective strains must be predominantly compressive? This is a long familiar but still much-discussed problem.[4]

A partial solution is provided by the known fact that, at any rate up to the end of Stage B in Fig. 1, the stress-strain characteristics of any given material are substantially the same for both tension and compression. That being the case, a very simple complete solution seems to be available if it is found possible to sustain the hypothesis, here submitted, that the "arrest point" of an indentation test is determined by the stabilisation beneath the indenter of lattice conditions associated with a characteristic content of stored energy, this characteristic energy content being itself determined by the location of the end-point of Stage B on the stress-strain curve—that is, the hypothesis will postulate that the "arrest point" marks the local attainment of a stored energy content characteristic of the virtual exhaustion of the capacity of the material for further elastic deformation.

The elastic behaviour here imagined will thus be closely analogous to that of an ordinary rubber air-cushion. The more strain-energy we pump into it before we sit on it, the less will be its capacity for further reversible elastic deformation, and the sooner our "arrest point" will arrive. In an indentation test, the simultaneous irreversible plastic deformation is here regarded only as providing an index to the capacity of the material to store additional energy of lattice strain.

Now, in Fig. 1, the total energy involved, per unit of volume, during the process of deformation along OYN, and then back to S (on removal of the external load), is given by the area OYNS. (It will be realised that in Fig. 1 the "elastic modulus" along OY, and the "spring-back" along NS, are both shown grossly exaggerated.) Most of this energy will be dissipated as heat, but a small fraction of it will be retained as stored energy of lattice strain. And experiment has shown that up to the end of Stage B, this residual fraction of strain energy will exhibit a substantially constant relationship to the total energy as given by the area OYNS.[5]

But in an indentation test carried out under fixed loading conditions, the depth of indenter penetration will itself yield a direct measure of the total work done, and hence also, neglecting minor frictional variations, of the potential addition to the strain-energy content of the region immediately beneath the indenter.

Therefore, if we put N = necking stress in the tensile test, S = necking strain in the tensile test, D = depth of indenter penetration in the indentation test, and if we provisionally assume that in Fig. 1 the "energy area" OYNS will depend directly upon the product (NS), we ought to have, at the "arrest point" of the indentation test,

$$a.D = b.NS$$

where a and b will be constants. We thus arrive at the relationship

$$D = c.NS \quad \ldots\ldots\ldots \quad (1)$$

where $c = (b/a) =$ constant.

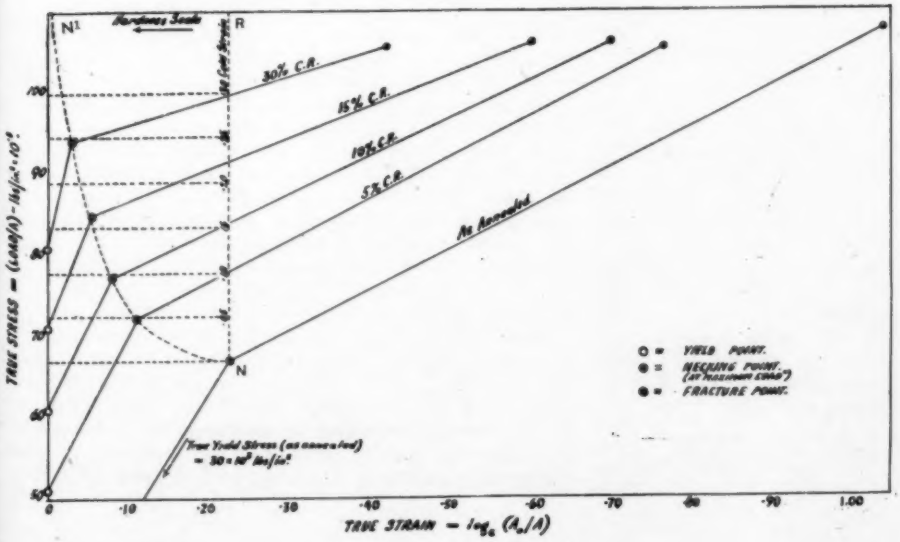
From this it follows that in Fig. 2, for any given value of the observed necking stress N along the curve NN′, the depth of indenter penetration D will be a simple linear function of the associated necking strain S. Equation (1) thus seems to provide a reasonably satisfactory explanation of the observed fact that in Fig. 2 the curve NN′ so readily lends itself to subsidiary interpretation as a Rockwell hardness curve. (NOTE.—In Fig. 2, MacGregor's "30 p.c. CR." data seem at first sight to yield anomalous "hardness" values. But MacGregor states that whereas his lower degrees of cold-reduction were all effected in one pass, the 30 p.c. reduction was made by six equal unreversed passes, which would give a "one-pass" equivalent in much closer accord with the "hardness" curve.)

In practice, however, things will not be quite so simple, because the area OYNS in Fig. 1 will not depend directly upon the product (NS), as provisionally assumed. This assumption would only be valid if the "yield-ratio" (between the yield stress and the necking stress) remained constant, whereas Fig. 2 shows that, as the elastic range increases with increasing initial work-hardening, the yield-ratio tends to increase, so that the "energy area," and hence also the depth of indenter

4 Vivian. *Proceedings of the Institution of Mechanical Engineers*, 1944, September, vol. 151, p. 105.
O'Neill. *Proceedings of the Institution of Mechanical Engineers*, 1944, September, vol. 151, p. 116.
Vivian. *Philosophical Magazine*, 1944, November, vol. 35, p. 765.

5 Taylor and Quinney. *Proceedings of the Royal Society*, 1934, vol. 143, p. 307.

Fig. 2.—MacGregor's stress-strain data. Low-carbon steel—flat section. Mean values along and transverse to rolling directions.



penetration, should tend to decrease rather more slowly than the observed necking stress increases. This means that measured hardness values will be expected to fall a little under the curve NN′ when the latter is viewed as a hardness curve.

The physical meaning here assigned to indentation hardness values would clearly lead to the practical conclusion that while they can tell us much about Stage B in Fig. 1, they can tell us very little about Stage C, except perhaps by dangerous inference. However, since Stage B determines the capacity of a given material for uniform deformation, it does seem possible to contemplate some sort of rational explanation of two long-familiar deep-drawing empiricisms—viz., (1) that high hardness values must generally be regarded with disfavour, and (2) that low hardness values do not necessarily guarantee satisfactory press-shop performance if the work locally demands any high degree of preponderant plastic strain in Stage C.

It would be going beyond the intended scope of this brief outline to embark upon a detailed discussion of the theoretical implications of the suggested hypothesis. It will perhaps be helpful, however, to stress that the physical interpretation proposed directly associates an indentation hardness value with the elastic behaviour of a given crystalline aggregate, i.e., with the characteristics of the ordered regions of the lattice. And since, as Bragg has pointed out[6], there will almost inevitably be some definite physical limit to the extent to which cold-work can induce changes in the ordered regions of initially "soft" material, it would appear to follow naturally from the present hypothesis that indentation hardness values should rapidly tend to a limiting magnitude at orders of strain associated, in the "as-annealed" condition, with the end-point of Stage B in Fig. 1. In an ordinary tensile test on annealed material, this end-point should mark the acquisition of a characteristic strain-energy content associated with the virtual exhaustion of the capacity of the material for further elastic deformation. If that same order of strain-energy content is induced in similar material by prior cold-work, it is obviously improbable that much additional strain-energy can be absorbed. Under such conditions, therefore, the "horizontal intercept" in Fig. 2 should clearly be tending to a minimum, and the measured indentation hardness should conversely be tending to a maximum. Fig. 2 appears to indicate that this is what actually happens; and the general picture seems to be in encouraging harmony with the experimental evidence which indicates that with the advent of Stage C in Fig. 1 the stored energy rapidly approaches a saturation value.[5, 7]

The preceding argument may at first sight appear to be invalidated by the fact that in Fig. 2, as the intensity of initial work-hardening is increased, the stress value at N does not represent the maximum value of the yield-stress attainable after prior cold-working, thus conflicting with the primary assumption that the capacity of the "soft" material for elastic deformation is virtually exhausted at N. A partial reconciliation between hypothesis and experiment seems to be provided by the additional observation that detectable necking of a tensile specimen begins before its stress-strain curve becomes closely linear in the final stage.[8] The physical conditions existing when necking starts in a tensile test would therefore appear to be comparable with the torsion conditions observed by Taylor and Quinney[5], where the stored-energy ratio was found to decrease very rapidly as soon as the most highly strained surface regions of their wire attained the physical state normally associated with the point of "maximum strength" in a tensile test. A more practical formulation of the proposed hypothesis might thus well be that the "arrest point" of an indentation test marks the localised completion of that stage of the process of mechanical deformation during which the stored energy ratio remains substantially constant.

It seems not unlikely, however, that the necessity for this tentative modification of the primary hypothesis may arise simply from the introduction of an arbitrary time factor into routine indentation tests. In the ideal case, Stage B in Fig. 1 should be non-existent; and elastic processes should be absent from Stage C, whose slope should be zero, as is actually observed in the later stages of plastic flow in compression. Therefore, the more the slope of Stage C departs from the horizontal, the greater must be the residual lattice content of potential elastic deformation, and the greater must also be the probability that the potential effects of these residual elastic processes will not be fully registered at the end of a short-period indentation test. This conclusion is in complete accord with everyday observation; but its theoretical basis, as here derived, should apparently lead directly to the as yet unorthodox corollary that it is the "fracture points" of Fig. 2, with their well-defined "saturation value" of the fracture stress, which will truly mark the limit of tensile liquidation of marginal elastic processes in the ordered regions of the lattice.

The apparently undeniable existence of a "saturation value" of the tensile fracture stress seems to demand that the conditions of tensile fracture shall be associated per unit of fracturing area with some characteristic distribution, both quantitative and qualitative, of the ordered and disordered regions. The simplest picture would appear to be one in which increasing tensile deformation is conceived as tending to the production of some limiting condition, not only of lattice "fragmentation," but also of preferred crystallographic orientation, in the ordered regions, accompanied by some characteristic atomic thickness of Bragg's disordered "transition layers"[6]. The same basis argument will also apply to compressive deformation, although it does not necessarily follow that the "saturation value" of the compressive stress will be identical with the tensile fracture stress. It is, however, a corollary of the argument that the arrest point of an indentation test, or at any rate of a long-period test, ought to be associated, in the region directly beneath the indenter, with a specific lattice structure whose characteristics should be substantially comparable with those of a specimen in which the saturation value of the compressive stress has been attained. There seems to be no ground for rejection of such a deduction, but no relevant experimental evidence appears as yet to have been recorded.

Lastly, it may be briefly noted that the much-debated "mysterious ratio" between Brinell number and "tensile strength" would appear to be one of the obvious predictions of the present hypothesis, from which it would directly follow that the two magnitudes concerned will represent nothing more than the numerical results obtained by assessing the same physical quantity in two

6 Bragg. *Proceedings of the Physical Society*, 1940, vol. 52, p. 105.
7 Seitz. "The Physics of Metals." (McGraw-Hill). 1943, p. 79.
8 Gensamer. "Strength of Metals under Combined Stresses." (American Society for Metals). 1941, pp. 81-2.

closely interdependent ways, this identical physical quantity being simply the characteristic strain-energy content (per unit of volume) at the point of "maximum load" on the stress-strain curve. This prompts the final thought that even if the present "to-start-you-talking" essay is found to contain major flaws or "dislocations," the time has now surely come when the problem here discussed, and all cognate problems, should be regarded solely as problems in the "physics of metals," and that all our reasoning on them should be essentially based on the fundamental physical differences that underlie the three well-marked stages of Fig. 1. By so doing, it seems not unreasonable to hope that we shall be able to make much more rapid progress than hitherto towards discarding quite a number of familiarly useful but none the less irritating empiricisms, whose very familiarity has unfortunately tended to retard the breeding of that benevolent contempt which is so long overdue. But, as Confucius said: "It is better to light one small candle than to curse the darkness."

Welding Various Metal Combinations With the Electric Arc

By O. M. White

Welding Development Department, Lincoln Electric Co. Ltd.

DURING the past few years every effort has been made to facilitate production and considerable ingenuity has been displayed in almost every production set-up to achieve this end. Many problems have arisen and are continually arising, which necessitates modifications to some accepted method in an effort to improve the product or to speed up production and some of these have been associated with the use of combinations of different metals in the same product. When these different metals require to be joined it has been found that excellent results can be obtained by welding. Typical combinations which are successfully welded include: Brass, or copper, to steel; cast iron to steel; and high-manganese to low-carbon steel.

Certain general conditions are to be considered in these cases. The weld joining the two metals will be of composite make-up, due to the dilution or in-wash of one metal by the other. The physical characteristics of this hybrid weld must be carefully considered in relation to the base metals. The heat effect of welding also affects the results. A third metal, deposited as a transition bead, may be used, and its effects must also be considered.

Brass to Steel

Assume that it is necessary to join a brass bar to steel plate with a lap joint. A bronze electrode is used. First, deposit bronze weld beads on the steel. These beads are then joined to the brass by the bronze electrode.

The electrode has a coating which shields the molten metal from the contaminating influence of the air and assists in the easy flow of the metal in the arc. The resulting deposit is homogeneous and of good tensile strength with the characteristics of true phosphor bronze. The electrode is connected to the positive pole of a motor generator type welder and the work to the negative pole with the following values:

Size.	*Arc Voltage.*	*Amperage.*
$\frac{1}{8}$ in.	22/26	50/125
$\frac{5}{32}$ in.	24/28	70/170
$\frac{1}{4}$ in.	24/28	90/220

For best results, the electrode should be held at approximately 90° to the work.

Cast-Iron to Steel

A suitable mild steel electrode is used for depositing a bead on to the cast-iron; there may be several layers of weld metal. This gives two steel surfaces, which can be joined by a weld deposited from a mild steel electrode. In some cases, where parts are not free to move or the cast-iron is rather difficult to weld, a special cast-iron electrode with a steel base is used to deposit the bead on cast-iron, which is then joined to the steel. In some cases, the transition bead is an entirely different metal, such as would be used in joining high-manganese steel to low-carbon steel.

High-Manganese to Low-Carbon Steel

Due to the characteristics of manganese, an 18 : 8 stainless steel electrode, having columbium in either the core wire or coating, is used to deposit a bead on the manganese and this bead is in turn joined to the low-carbon steel by a stainless steel electrode. The stainless steel transition bead can also be joined to the low-carbon steel by a steel electrode.

These examples illustrate the use of transition or intermediate beads, and suggest that when two dissimilar metals are to be joined, an electrode should be selected which may be easily and effectively deposited on one metal to form a surface, which may then be joined readily to the other. Due regard for physical properties and heat effects upon these combinations of metals must be taken into account. Numerous problems are solved by this method of using transition beads.

Surfacing for Increasing Service

Although surfacing by welding was used mostly for salvaging worn equipment in the early days of welding, the process is recommended and economically employed in applying effective wearing surfaces to new equipment during manufacture or prior to use.

The application of surfacing by welding should be considered from the viewpoint of service life of the equipment. Any piece of equipment must perform satisfactorily and meet certain definite load conditions. Service life, measured in performance and cost of that performance, must be adequate. This performance may be obtained either by making the entire part of a given kind of metal, such as steel, or by using one metal as a support and another to receive the load and wear.

Four definite reasons for the use of surfacing in the fabrication of various types of equipment are:—

1. It improves service life.
2. It reduces overall cost.
3. It decreases cost.
4. Dimensions are maintained within fairly narrow limits when surfacing is used as compared to a single metal.

The service life of equipment involves the load conditions to which the parts are subjected. These loads may be classified as to rate of application of the loading, such as uniform, impact, and vibration. Other factors affecting service life include wearing conditions, such as abrasion or corrosion and conditions of temperature. Under impact loading the time rate of application of the load is important. The impact effect of a slow-moving train on the rails as it traverses a crossing is very much lower than that of a train travelling at high speed. In another instance, impact may be momentary, as in the case of a shovel tooth striking a rock, or a cam operating in a machine. In considering wear, abrasion is usually regarded as a grinding action, as when operating in sand ; or a sliding, rubbing or rolling action, as when one metal moves over another. Corrosion involves gas or atmospheric conditions, as well as liquids and, in some cases, the action of solids. Operating temperature also affect service life.

In so far as surfaces deposited by arc welding are concerned, another consideration is important. This is the condition of the surfacing metal immediately after it is deposited. The surface either possesses its complete characteristics as deposited, or it must receive some subsequent treatment. For example, one surface may be hard as deposited, while another may require peening to obtain the desired hardness ; or, in another case, the surface may require heat-treatment after deposition. Thus surfaces may be classified under two groups :—

1. Load Conditions.
2. Condition of the surface after deposit ;

the latter being a factor in considering load requirements.

A Cylinder Block Washing Machine

THE thorough cleaning of every nook and cranny in the complicated interior of cylinder blocks has been a source of trouble in motor-car and aero-engine factories since their development. The recent development of a cylinder-block washing machine is claimed to perform this operation. It is designed to remove oil, grease, sand, machine filings and generally thoroughly clean cylinder blocks in the assembly lines of automobile and aero-engine factories.

The machine, which has been developed by Messrs. Curran Brothers, of Cardiff, is covered by patents and comprises, in the main, two sets of powerful jet systems, one of them fixed and the other mobile. Both are supplied with hot detergent solution circulated by a single pump and filtered during process. The mobile jet system scours the inside and outside of the cylinder block simultaneously, operating with an up-and-down motion, whilst the fixed jets are arranged to deal with blind holes. Cam shaft bearings, oil grooves and channel, etc., are thus searchingly probed by the hot solution. When the solution has done its work, cams actuating the control valve close the supply of solution and open another valve releasing compressed air into the same piping which dries and cools the block, blowing out solution left in blind holes, etc.

Cylinder blocks coming from the machine lines of motor car factories have to be thoroughly cleaned before passing to the assembly lines. It is essential to remove foundry sand, swarf of various kinds, and dirt which accumulates in all parts of the block during fabrication, and which becomes embedded into position by congealed oil and grease. The blocks are received at the machine on the roller conveyer of the production line, a section of which forms a turntable immediately in front of it. The table is revolved so as to present the cylinder block endwise to the washing machine, and a gentle push from the operator drives the block into the washing chamber.

The door of the chamber is closed, and the start button depressed, and the block is automatically washed, dried and cooled. When this is complete the operating motor trips out and the machine is ready for unloading. The door of the chamber is opened, the block withdrawn, swung round again on the turntable and sent on its way to the assembly line, the washer now ready to receive another block. The whole operation can be carried out in minutes.

A machine designed to remove oil, grease, sand, machine filings and generally thoroughly clean cylinder blocks in the assembly lines.

The washing machine is of all-welded construction and, as can be seen from the accompanying illustration, is a very self-contained compact job. The feed door is hinged at the top and balanced to maintain it in any position. The driving and control mechanism is contained in the cabinet at the back of the machine and is readily accessible through the swing doors provided. A thermometer shows the temperature of the solution which is thermostatically maintained at 80° C. Sodium metasilicate solution (" water glass ") has been used very effectively and economically in the washer.

The output from the machine will naturally depend on the state of the block presented for cleaning.

The Shape of a Material's Reactions to Force—Part II.

A. C. Vivian, B.A., D.Sc., A.R.S.M.

In Part I the writer dwelt on past misapprehensions which have hitherto denied the possibility of one standard stress-strain curve of a material standing as a representative of all its "elementary" mechanical properties; he showed how "compound" properties might be calculated as soon as their analyses have been completed. Two of these "compound" properties have already been so well analysed and understood that they may now be calculated from the data of the stress-strain curve. Some type of coefficient for use in converting the standard (normal temperature and time) curve to the shape prevailing at other temperatures and loading rates should ultimately be devised, when the applicability of the new proposals will be quite universal to materials worth the name.

IN the widest possible sense, the word "material" would cover almost any solid, liquid or gaseous element, compound, mixture, solution, or firm or loose aggregate. To what degree should the process of narrowing the definition of "material" be taken? Should a beginning be made with "structural materials," and should these include brick, stone and concrete as well as the metals? Can the metals be said to constitute a single class of materials, seeing that they may even include forms of matters as divergent as single crystals, finest and firmest aggregates of identical crystals, comparatively coarse and loose aggregates of greatly differing crystalline matter, electrolytic deposits, and even the products of "powder metallurgy"?

Technical versus Scientific Approach

There are no perfectly satisfactory answers. The comprehension of the mechanism of cohesion and innermost reaction to force in the great diversity of "materials" is, beyond doubt, an enormous undertaking upon which the pure scientists are at work. Even to-day it is not known with any certainty what are the forces in equilibrium which produce the regular crystalline lattice spacing, for example. But, that understanding to comprehend the innermost meaning of cohesion and reaction must surely be considered as of scientific rather than of technical or immediate practical importance. The pressure-volume curve of gaseous reaction to force, for example, is in itself a simple experimental result of the greatest technical and practical significance, quite apart from its ultimate dependence on pure truths or underlying "scientific facts." This curve derived from a practical test is easily to be had and greatly to be valued whether the Maxwellian or the kinetic theory be true! In the same way, the really significant stress-strain curve of a metallic aggregate's reaction to load is of the greatest technical and practical value even though pure scientists have hardly begun to discover the nature of the forces involving that equilibrium known as the "lattice."

As a further example of this important point,—which seems to have escaped attention in quarters both scientific and technical,—the case of electrical development may be cited. The practical electrician—and surely even the scientific electrician of the purest type—derived unending satisfaction and advantage from experimental results and their curves long before he could hazard so much as a guess as to the nature of the electric "fluid" which his "pressure" or E.M.F. appeared to be driving round his circuit. The most brilliant article by the most prominent physicist upon the effect of external force on the particles of a metallic lattice could never be considered a response, as a quietus, to the writer's plea that technical and practical men have paid all too little attention to the possibilities of the stress-strain curve as a true representative of all the mechanical properties. It would seem that technical and practical men, including mechanical engineers and metallurgists, primarily and urgently require that the materials should be made to exhibit their true stress strain curves at once, and (if necessary) long before scientists and mathematicians have concluded their own invaluable researches into inner truths. In the opening phases of the new study of "Rheology" in this country there has also appeared an incipient tendency, which in this case will probably not develop into a fault, to assert the mathematical side of the subject when it would seem unlikely that this side could handle more than a practically non-existent hypothetical material. The technical and practical man cannot await the results of protracted and difficult researches before availing themselves of simple tests to provide curves of stress and strain, of viscosity, and so forth.

The Curve-Shape in Rheology

With this introduction to the definition of a material, it is hereby suggested that all materials whatsoever may be persuaded by tests to sign their responses or reactions on paper before ever scientists and mathematicians have decided why they so sign themselves, or for that matter even if the reason for the signature's strange shape is quite well understood. Hence, the new study of "Rheology" seems to be merely part of a comprehensive study of materials in general, and would seem to call for determination of stress-strain curves in circumstances which usually demand more attention to rate of loading, so as to procure viscosity curves rather than stress-strain curves. There is no essential difference at all here: it so happens that many familiar structural materials display stress-strain curves which change their shape remarkably little on change in rate of loading, while the materials of more particular interest to rheologists change shape so much with change of this rate that a particular feature, viscosity, seems to have more significance than the simple stress-strain relationship. Thus, the "time factor" is more important for rheologists than for mechanical engineers and metallurgists; though the

latter would make a mistake in supposing the time factor plays no part in the shape of their own materials' reaction to force. A knowledge of the viscosity of steel and other alloys at forging (etc.) temperatures would seem to be most valuable. Meanwhile, the " compound " property viscosity should be one easily calculated from the stress-strain curves taken at a variety of loading rates at the desired temperature. The understanding of, and the calculation for viscosity would thus appear to be as simple as in the case of toughness. (see Part I.)

A Simple Hypothetical Material

In order to take the most comprehensive grasp of the shape-change of these curves as it varies from that of the elastic solid to that of the mobile liquid, or even to that of the gas, let it be assumed for temporary convenience that some material had solid characteristics including elasticity at low temperatures ; that at raised temperatures it exhibited no melting point, but passed gradually over to an elastic-cum-plastic solid, then to an almost solely plastic solid, next to a practically viscous liquid, next to a mobile liquid, and finally (without sudden boiling) into a gas. There are substances not very unlike such a hypothetical substance which has neither melting nor boiling point : in any event such a substance would not be " against Nature," and its behaviour is worth considering. If it were a material it would not be easy to say at what temperature it began to be a material and at what temperature it ceased to be one ; for its transition from the property of almost pure solid elasticity to the property of the " perfect gas " would take place in a great number of infinitesimal steps as the temperature rose. In short, the stress-strain curve of such a material would change imperceptibly from the steep inductile shape of the elastic solid, through the elastic-cum-plastic shape, and the plastic shape, to the horizontal viscous shape, the last getting lower and lower as temperature reduced the viscosity to the " perfect gas " form of the material. To complete the picture, it should also be mentioned that the time factor (loading rate) would, within ranges of rate considered large) have conparatively little effect on the shapes of the low temperature curves, but would have growing effect with increased temperature, until its effect at the higher temperatures became enormous, causing " viscosity " to be the most important and familiar reaction of all.

Now, this hypothetical material is cited just because it possesses a most unusual continuity of existence and of behaviour through a wide temperature range. In reality, the only difference between this hypothetical material and any ordinary material is a question of continuity of being and of behaviour. Familiar substances, which within some temperature range are called " materials," at higher temperatures commonly undergo one or other of the many possible " changes of state " which destroy this continuity suddenly, or else are altogether changed by some stage of decomposition into completely different substances. Thus, at low temperature a substance may have one particular " allotropic " form, or be in a highly condensed molecular and solid state ; at higher temperatures it may suddenly change allotropic form, or suddenly assume a less condensed solid state ; at still higher temperatures melting may take place suddenly ; then perhaps another allotropic change may take place suddenly in the liquid state ; at a still higher temperature boiling may occur suddenly. Meanwhile, at any stage whatsoever from beginning to end of such a temperature range the original substance may by dissociation or decomposition become two or many more utterly different substances.

It is just this very familiar discontinuity of " state " and of " existence as the same substance " through a large range of temperature that has limited the outlook on materials and on their stress-strain characteristics. For, if on raising the temperature from some low point a change of state takes place or decomposition occurs, the discontinuity of state must necessarily be accompanied by discontinuity of all properties including discontinuity in the shape of the stress-strain curve which reflects the mechanical properties. The stress-strain curve of the solid pure metal gradually changes (in the manner indicated for the hypothetical material) as the temperature is raised until a change of allotropic form or of state occurs, when this process of gradual change in curve-shape gives way to a sudden change of curve-shape. If the change of state be allotropic, its curve-shape change may not be so very great ; but a melting point or boiling point change will usually produce so profound an effect on the curve-shape,—will, in fact, advance its shape so far in the direction indicated by the hypothetical material—that no connection whatever may be seen at first between the properties of the metal before melting and after melting. There is a connection, however, which is simply the distance apart of the atoms of the metal. For, the gradual increase in distance due to increased temperature produces the gradual curve-change ; whereas the sudden increase in distance (accompanying change of state with the usual absorption of heat energy) is accompanied by a change in curve-shape commensurate with that increase in distance which is very considerable in the cases of the melting and boiling point changes.

When the case of an alloy is considered, the possibilities of change of state are increased : a two-phase alloy may change to a single-phase alloy on change of temperature, with a correspondingly sudden change of curve-shape which again is connected with the prior curve-shape by considerations which no doubt equally involve average distances between unlike atoms. No attempt will be made now to elaborate this particular theme, though it may prove worthy of development.

Definition of Structural Material

Any mass of matter employed or employable as a direct or incidental means of transmitting force would, up to the present, seem to be a " material " within the meaning of the word in this particular article. To take very extreme cases, a material may be as coarse, loose, weak, and heterogeneous as rubble, or may be as fine, firm, strong and homogenous as austenite, bronze, glass or perspex. It may be isotropic like annealed metals and glass, or anosotropic like wood and strained metals. As it is required to react to force, it is reasonable enough to apply tests—on specimens of size sufficiently representative of the masses actually employed, having regard to the coarseness of the material—which would appear to determine the material's performance in actual use.

Now, the specific requirements of materials called upon to exhibit reactions to force have for long been grouped into a class of properties known as " mechanical." The metals happen to be unique in two respects—between them they exhibit an unusually wide range and variety of these properties, and industrially they are of the greatest value as materials. It is therefore not uncommon

to find that metallic examples are chosen to illustrate the mechanical properties and their meanings, though the metals constitute no class of materials from the standpoint of the mechanical properites. The wide range of properties may be appreciated in such metals as iron, aluminium, tin and lead ; more particularly in the last two, every property from nearly complete elasticity to nearly complete fluidity is to be seen on the one true curve. The variety is noticeable in the difference between the curves of strongest steel (martensitic) on the one hand, and lead on the other. This is the very denial of any claim that the metals constitute any class of materials, because all of them can be fairly matched by non-metallic materials—as far as the curve-shapes are concerned.

On the stress-strain curve of the very ductile metal is to be found, however, every conceivable exhibition of properties classed as " mechanical " from almost perfect elasticity to almost perfect fluidity even before melting (e.g. lead). Yet, within the ranks of the metals is to be found an enormous variation of coarseness, fineness, looseness, firmness, weakness, strength, heterogeneity and homogeneity. Rather than compare coarse grey cast iron with martensitic steel on the grounds that they are both ferrous metals (and might therefore be supposed to have mechanical properties in some way comparable), it would in reality be safer to compare coarse grey cast iron with rubble, essential as the former may be for many uses. Between coarse masses of matter as dissimilar as graphite, cementite and pearlite there cannot be the great force of cohesion to warrant comparison between mechanical properties of ordinary cast iron and the ductile metals. A mass of rubble is certainly stronger in compression than in tension : compressive force in a material consisting of heterogeneous incoherent particles will have the effect of bringing those particles into appreciably closer contact, whilst tensile force would have the opposite effect. In consequence, frictional resistance to shear can prevail to a greater extent inside that mass upon the induction of compressive stress.

If, however, as in fine homogeneous materals of almost any kind, the mass's atoms have set themselves in equilibrium at distances apart of the same infinitesimal order as the size of the atoms themselves ; and if the cohesive forces of this equilibrium which govern these tiny distances are as colossal as would be expected, any appreciable disturbance of these equilibrium distances would call for colossal stress induction. It could then be assumed that even upon the induction of axial stress considered very large (but not colossal) the atomic distance must remain at least practically, though not literally, unchanged. In which case, friction at shear planes would not only be vanishingly small (seeing that atoms are never in contact) but would be practically identical whether the axial stress induced were tensile or compressive. The tensile and compressive axial strains must, then, both be the result of shear slip strain. To describe friction as " vanishingly small " is not to say that the shear stress required to produce atomic shear displacement is negligible, but only to say that the effect due to the contact between rubbing surfaces is negligible in the fine homogeneous material, and appreciable in the coarse heterogeneous material in which cohesive forces may be very weak locally.

Cohesion and Curve-Shape

When tensile and compressive reactive effects are both the result of practically identical shear reaction, they must obviously be equal to one another. It should be clear from the following that the equality of tensile and compressive effects in a material is, without it being fully realised, a criterion of a material's excellence. For, cohesion is acknowledged as a *sine qua non* in a material ; and yet, as soon as the lack of it causes working axial stresses to approach the order of magnitude of the cohesive forces, shear friction will be appreciably greater in compression than in tension, and the compressive stress-strain curve will come to differ to that degree from the tensile stress-strain curve. Hence, the difference between the curves in tension and compression is a criterion of the material's cohesion. Again, porosity is acknowledged as a quality to be avoided where the best mechanical properties are called for ; and this would also be accounted for on the grounds that tensile resistance of porous materials cannot be so good as it would be in the same non-porous material. Here also compressive stress would be greater than tensile stress (for the same strain), tending to bring rough inner surfaces into better contact, thereby introducing the friction not present in the non-porous material ; and the difference between the two curves would be a criterion of the material's shortcomings in respect of porosity.

It will be seen that something rather vital emerges from the above. Is the claim justified that one and only one true stress-strain curve may stand to represent all a material's mechanical properties ? It would appear not —unless the definition of " material " is narrowed down to the point at which the compressive and the tensile curves are identical in shape ! Returning to the opening paragraphs of this article, it will be seen that the widest possible meaning of the word " material " was accepted conditionally, and yet a definition as wide as the widest is most unsatisfactory, classifying rubble and steel in the same category. If, however, it is accepted that the aim of all manufacturers of materials is to procure cohesion compared with which the axial stresses to be induced in use are very small ; and if in fact this end is achieved as a general rule whatever the type of " material," then it would perhaps be quite fair to define a " material " as a mass of substance, used directly or incidentally by virtue of its reactions to force, for which its compressive and tensile stress-strain curves are practically identical.

In the many and varied processes of manufacturing and preparing materials of all kinds, it is recognised that free setting from the molten state may do everything possible to establish maximum cohesion if porosity can be avoided. In other materials, the atomic and molecular structure is assisted to adopt the cohesion necessary in the material by the use of hydrostatic pressure, or equal loading in three principal directions at the same time, for the necessary consolidation. In others, again, impregnation may be adopted with the object of procuring greater cohesion in a less coherent mass by some kind of glue. The suggestion is that all these materials may rightly be termed " materials " because, within the stress limits of their intended use, their compressive and tensile curves are practically identical. Beyond the range of their intended use they would no longer be " materials." By that criterion, ordinary cast iron is a perfectly good material in every way until it is used at stresses at which it is never supposed to be used. Nevertheless, it would appear to be safer on the whole to compare ordinary cast iron with rubble than to compare it with another ferrous metal with completely different cohesion ; safer, that is, until it is thoroughly grasped

that a ferrous base to a structural material argues as little as any metallic base can about the mechanical properties of the material when the most important feature of all in a material is its cohesion. The mechanical properties of an electrolytic deposit of, say, copper, or a " powder metallurgy " product of copper particles, must depend primarily on the cohesion of the particles which, in either case, may vary greatly. The fact that practically pure copper is present in every case is no guarantee of mechanical properties nor is it any guide at all as to what to expect. In point of fact, it is at least theoretically possible to obtain an electrolytic deposit of copper so fine-grained and coherent that its strength would be higher than that of the strongest copper produced by melting and cold-working. On the other hand, very loosely coherent deposits may be produced which are weak. Now, for certain purposes of transmitting force, even the loosely coherent deposits may be suitable : for other purposes, even the most tightly coherent may be not strong enough—steel would have to be substituted for the copper. But still, it is submitted that the loosely coherent deposit of copper which had its structural uses could be classified as a " material " for use within the ranges of stress in which the tensile and compressive curves were practically the same.

Shape-Change on Metallurgical Treatment

In a previous issue the writer dealt with this treatment aspect of the whole question in an exploratory way, pointing out that metallurgists have, at rock-bottom of their treatment, the single crystals of their metallic bases. To take one metallic base at a time, its single crystal is not a practical treatment basis but only a theoretical one. A very coarse-grained metallic base is the " lowest common denominator " of metallurgical treatment ; and this has a certain long low stress-strain curve, characteristically differing from the corresponding curve of a comparably coarse-grained specimen of an other metallic base.

How, then, does metallurgical treatment affect this basic curve-shape of the coarsest grained metallic base ? It has been suggested that treatment—for obtaining modification of mechanical properties—could well be classified into :—

(i) Grain refining.
(ii) Cold working.
(iii) Preparing atomic solutions (simple solid solutions).
(iv) Preparing solid solutions at high temperatures which develop other phases, at low temperatures, which are molecular solutions.
(v) Preparing a mixture of phases.

Metallurgical treatment has its origin in the distant past, and suffers on that account from obscuration, from the drag of preconceived notions and inept terminology. Treatments thoroughly familiar to-day, and seemingly elementary because they are so familiar, are in fact complex according to the simplest analysis as above. The very common expression " hardening " is quite unfortunate, for example, being applied where nothing but " strengthening " is really intended. Often, the very last intention of the so-called " hardening " process in treatment is to convey the property of hardness itself —though hardening must follow strengthening.

Whatever the present-day treatment, it is compounded of, can be analysed into, the above. Cold working is not invariably present, but grain refining is often both deliberate (at one stage) and incidental (at another). The alpha solutions, or any incidental simple atomic solution of metals, are familiar in the brasses, bronzes, and ferrites. The molecular solutions, such as the steel transition products, heat-treated Duralumin, etc., are particularly sought after because molecules in the metallic lattice are not so unyielding as atoms for the same degree of endowment of strength : they conveniently dissociate under excessive stress-induction, giving greater ductility for any degree of strength, greater toughness before fracture.

Each taken apart, the classes (i) to (iv) above do nothing but make the long low curve-shape of the mechanical properties of the coarsest grained metallic base into a shorter higher curve-shape, giving greater strength at the sacrifice of ductility. The contradictions which can readily be quoted are only apparent, not real, the trouble being that we have stumbled on our knowledge of treatment, and do not always see what it consists in. If, for example, we expect a straightline law of strengthening with grain refining, we should be disappointed. In point of fact, there does not appear to be a great amount of strengthening on grain refinement within the range of common refinement in steels, though below and far above that range it is to be found—particularly below, as though the strengthening law were logarithmic.

Again, so many atomic solutions (such as the brasses and nickel ferrites) contradict the statement that class iii treatments give strength at the sacrifice of ductility. Here it has to be realised that the assumed treatment base is literally pure though in practice it never is, and complications are liable to result. If, for example, literally pure copper were used in the preparations of brasses, it could never be said that atomic solutions of zinc in copper increased the ductility of copper.

We are prone to view the pearlitic steel as quite a simple proposition ; but that is merely because we have stumbled on iron-base alloys, and chanced to manufacture this kind of steel from very early days. From the standpoint of mechanical properties pearlitic steel is comparatively complex, and it is really small wonder that this commonest structural material to-day behaves like an *enfant terrible* with the crop of questions it raises.

As an introduction to a discussion on the stress-strain curve of pearlitic steels consider first an alpha-beta brass. The latter has grains of two atomic solutions of zinc and copper in equilibrium, each of these having its own stress-strain curve. When grains of these two are mixed, as in alpha-beta brasses, the resultant stress-strain curve must be a compromise between the curves of the individual grains ; but it would not be difficult to see that only very fine-grained aggregates of these phases would approach the theoretical compromise, the coarser the grain the more the compromise would lean towards the mechanical properties of the weaker phase.

Up to pearlite itself, pearlitic steels presumably have stress-strain curves which are compromises between the curves of the ferrite (an atomic solution) on the one hand, and of the pearlite (a two-phase alloy) on the other. The coarser the grain, the more the properties lean towards the properties of the ferrite—hence the value of annealing for easy machining, for weakening in short. Pearlite itself must be said to have a stress-strain curve which is a compromise between that of ferrite and that of cementite, the latter reinforcing the former. Again, if spheroidisation takes place, not only cementite coarsening takes place but reinforcement is removed, and the

alloy is weakened for easy machining, etc. The ferrite can now flow round the stronger cementite particles, so the latter do not make their full contribution to the composite stress-strain curve. Where one phase is so much stronger than another phase it is particularly easy to see why coarsening the grain of a two-grain (or two-phase) alloy will weaken the alloy.

In spite of the above, however, there must be a determining feature of even greater importance, in the case of a multi-phase alloy, than the compromise between the stress-strain curves of its phases. That feature is the cohesion between the phases. It might be assumed, perhaps, that there is no lack of cohesion between the alpha and beta grains in brass : pearlite is so largely of ferrite that it might perhaps be assumed there is no lack of cohesion between grains of ferrite and grains of pearlite. As to the amount of cohesion in these cases, nothing seems to be known. But, as between free cementite and ferrite (or pearlite), the cohesion is known by experience to be poor : there is so large a difference between a metallic compound and the metal itself that cohesion seems unlikely anyway. Similarly, the feature determining the mechanical properties of ordinary grey cast iron is almost certainly the cohesion between the graphite, the cementite and the ferrite (or pearlite). This question of the forces of cohesion between grains is known by experience to be vital to mechanical properties ; as it has already been seen, it cannot possibly be ignored when lack of cohesion produces a significant difference between the stress-strain curves of tensions and compression within the ranges of stress-induction intended for the material. Once more, however, the writer returns to the point that a difference known to exist in some cases between the tensile and compressive curve of a material is no repudiation of the claim that, in all materials worthy of the name, there is no difference between the curves of tension, compression, and shear in the " working " stress range.

The Sudden Yield of Iron and Steel

On contemplating the progress of discovery, amazement may often be occasioned by the perversity with which a subject seems to have hidden away its secrets from the gaze of the curious. This is a case in point : one of the first structural materials to have its curve of stress and strain plotted and examined with deep interest must needs be the only one to exhibit a freak result, an extraneous feature, the nearly straight line from the origin surmounted by the sudden yield point ! For some time, iron and steel were regarded as typical metals, and these observed mechanical reactions were therefore taken to be typical of metallic materials. Many technicians still believe that the " straight " line commencement of the curves of iron and steel, and the sudden yield, require no special explanation because they are definitely characteristic of these materials, if not of all metallic materials.

From one limited point of view they could be said to be characteristic, but from a broader one they are not. They might be described as characteristic, perhaps, in the sense that iron and steel are still manufactured without the precautions necessary to obtain a product with less erratic behaviour under load : they are not characteristic because they are due to a casual impurity which can be, and often is, removed nowadays from these metals. Copper containing extremely little bismuth gives a much curtailed stress-strain curve. Is this latter characteristic of copper ? If not, could it be claimed that the sudden yield of iron and steel is characteristic of those alloys In the production of the modern " stabilised " steels of America, or of the Izett steels of Germany, such sudden yields have been disposed of.

As some might think that this question of the sudden yield is one of the " past misapprehensions " which the writer has not faced squarely in his Part I, it is now due for consideration. It might certainly be felt that if some stress-strain curves exhibit the sudden yield, and some do not, things cannot be capable of simplification as the writer imagines !

A complete explanation of this sudden yield effect does not appear to have been supplied yet ; but it is known that a more thorough removal of oxygen from the iron in manufacture removes the sudden yield somehow. It is presumed that the removal of oxygen prevents a metastable solubility of carbon in solid ferrite, and so prevents a molecular precipitation of carbide from the ferrite in the early stages of loading, prevents a precipitation and continuous strengthening under load which, when it occurs, not only makes the first part of the curve extremely straight, but stops more or less suddenly when all the carbide is precipitated, producing a sharp discontinuity.

This is the same precipitation-strengthening effect as takes place under load in Hadfield's manganese steel, or in any metastable austenite under load : an atomic solution of copper in ferrite is also supposed to strengthen steel by precipitation to the molecular form. In the case of the common (unstabilised) iron and steel, the stress-strain curve starts with the precipitation-strengthening effect superimposed on the normal strain-strengthening effect, and the result is the apparently straight line which stops suddenly at the " yield " when the precipitation ceases to add its effect to the normal effect. Not only is this precipitation noticeable in the stress-strain curve, it is seen also in the S–N curve of the fatigue test which, in the case of iron and steels alone, run on a practically horizontal line for a great many million reversals at " safe load." No other metallic materials exhibit either the exceptionally straight line to the yield, or the practically horizontal S–N curve at " safe load " ; and there is good reason to suppose that both of these effects are quite uncharacteristic of materials, and due to the same incidental cause.

The really uncharacteristic part of the behaviour of iron and steel in this respect is the discontinuity or break in the curve at which the material suddenly ceases to behave like one material to behave like another. There is no saying how many alloys exhibit similar and incidental precipitation-strengthening ; but presumably the effect, if it occurs in other cases, is never so strong as in iron and steel, and draws attention to itself neither by producing a remarkably straight part of the curve from the origin nor by stopping short suddenly. Where precipitation-strengthening is well known to be present, on other occasions, e.g. Hadfield's manganese steel, the nearly straight part of the " limit of proportionality " is of considerable length, but the precipitation presumably continues at much the same rate right up to the point of fracture, and there is no very marked discontinuity in the curve.

Seeing, however, that such a large range of iron and steel products, even the " stabilised " specimens, exhibit stress-strain curves which come away from the initial fairly straight part rather quickly—not quite as smoothly as might be expected,—the writer hazards the opinion

that ferritic precipitation-strengthening is widely prevalent in iron-base alloys of ferrite or ferrite-pearlite, and is not actually suppressed in the " stabilised " steels, in the high carbon steels, and in the alloy steels ; but is only caused to stop less quickly, made to finish more gradually.

This mere accident, as it were, by which alloys of the metal base first examined with care exhibit an approximately straight-line part of the curve for some distance seems, by a freak of natural adversity, to have been responsible for misconception concerning elasticity in the metallic aggregate : it held the promise of a truly elastic range in metallic materials in general, it gave rise to conceptions of the constant elastic modulus, the limit of proportionality, the proof resilience, and the point of mechanical failure. Yet, literally, there can be nothing of the kind—even in those ferrous products which exhibit the most sudden of yields. For, although the early part of the curve of such products may appear straight enough on the curves commonly seen, the strain-scales we commonly employ are much too closed-up for proper judgement to be passed on the question of elasticity in these products. If we were to see these curves on very open strain-scales, we should have a different story to tell. There is good reason to suppose that the stress-strain curve must be logarithmic in shape ; and, straight though some parts of a logarithmic curve may look to the casual observer, no part is literally straight of course.

The Logarithmic Curve-Shape

The logarithmic form is characteristic of the stress-strain curves, and the necessity for this shape is inherent in the mechanism of change and recovery operating when a material is loaded. An unloaded material is one whose particles have established themselves in equilibrium of a kind, which is disturbed by the application of a load : in the latter disturbed state there appear to be two alternatives. Either the original equilibrium was really true, particle for particle, as in the case of a perfect crystal lattice, or the equilibrium was merely statistical referring to the particles as a whole rather than to individual particles many of which are but in mobile equilibrium with one another. Where the original equilibrium was perfect in detail as in the case of a theoretically perfect single crystal of a metal, a true, even if a very short, elastic range is anticipated and is actually to be found. Wherever original equilibrium (before loading) is merely statistical or average, not applying in detail to every particle of the material, the effect of load is to produce a particle displacement, a permanent set depending on lapse of time as in the case of a viscous liquid, through the fluid rearrangement of those particles of the material which are only in mobile equilibrium with one another.

In other words, only single crystals can be considered as having the structure of " pure solids " : any other substance, even an aggregate of crystals, must be viewed as partly fluid, capable of flow under load from the effect of the lightest load in time like a viscous liquid. If there is any difficulty in visualising this part-fluidity in the case of the metal aggregate, it would be as well to remember that grain-boundaries are not crystalline ; or, if they must be described as " microcrystalline," then it should be remembered that the unorientated microcrystalline state is obviously a state leaning towards the amorphous or fluid state. It is certain that grain boundary matter cannot be brushed aside by the simple process of making more of it !

When loading is gradually imposed, as in the tests for a material's elementary mechanical properties to chart the true stress-strain curve, its energy is stored by the whole material elastically and at the same time is gradually dissipated into heat as time permits of the viscous flow taking place among the particles merely in mobile equilibrium. Evidently, then, the shape of the curve must depend on the time of the test, being longer for a given height in a protracted test ; but there must be a limit to the rate of smooth flow in the viscous element of the material beyond which rupture must follow (through eddy current formation and gross disturbance), and this will limit the maximum stress before rupture at any particular temperature. The curve-shape is greatly dependent also on the amount of " relaxation " or breaking down of the actual structure of the material under load, and upon its recovery sooner or later before the end of the loading. In metallic aggregates, the individual crystal grains suffer destruction at glide planes forming slip bands of amorphous or of microcrystalline structure (which is much the same thing) ; and in some aggregates recovery takes place almost immediately during the test so that the material is almost infinitely ductile or fluid in behaviour, at least if the loading is not too fast. Creep can be nothing but the flow, in time, of the viscous elements which are too viscous to flow in the time and at the temperature of the common test ; and the phenomenon of creep should make it clear enough, even to the most fanatical believer in the elastic range of a metallic aggregate, that there can be no literally straight part of the stress-strain curve, though in many instances it may be convenient and safe enough to assume the existence of one. An instance in which it is highly dangerous to assume elasticity is seen in fruitless attempts to discover, by experiments on metallic aggregates, the most satisfactory formula for assessing mechanical failure ; for, in these materials, failure must take place literally from the very commencement of loading, becomes gradually more marked until it is quite definite, though it is impossible to locate a point of mechanical failure.

In a logarithmic curve, $y=x^n$; or, if f is the stress and s is the strain, $f=k\cdot s^m$, where m is some power of s, and k is a constant. This can only be the equation for a straight line when $m=1$; yet the early part of curves $f=k\cdot s^m$ appear to be nearly straight when m is either a small fraction or of high value. True stress-strain curves have the logarithmic shape $f=k\cdot s^m$ where m is a small fraction, and this means that stress increases at an ever decreasing rate compared with the strain. This might be described as a " dying away " of stress increase per increment of strain induced, or else as an increase of strain per increment of stress-induction. But it is conveniently considered as the " dying away " curve, because it represents the gradual dying out of " elasticity," of the capacity at the very zero of loading, to store energy reversibly which is (literally) merely an abstract capacity in the case of materials.

Substantially, then, the inherent logarithmic shape of the typical stress-strain curve is due to a gradual relaxation change of the material itself until there is, progressively, less and less unchanged material to affect. The material under test is compelled by the effect of load forces, deliberately added to its original equilibrium forces, to requisition or draw off from its static equilibrium elements particles to swell the number

of those in mobile equilibrium ; until, at the displacement velocity occasioned by the stress attained, smooth flow breaks into chaotic flow and rupture. It has been seen that relaxation takes time, that recovery after relaxation is not only possible but common, and that also takes time. It is evident that the curve-shape may reflect every combination of relaxation and recovery times, and will vary with the temperature and with the rate of loading in a truly complicated manner.

Yet this stress-strain curve is in itself a readily available graph of the mechanical behaviour of materials, sublimating in pictorial form the whole of the scientific and mathematical reasoning which will, one day, completely account for it !

Reviews of Current Literature

A Structural Engineer's Compendium

To those readers familiar with the edition of this compendium, published several years ago by the Appleby-Frodingham Steel Co. Ltd., the edition recently published will be especially welcome ; to those not familiar with the previous edition, excepting through friends or business colleagues, the new volume may well be regarded as a cherished possession, particularly among civil engineers, structural engineers, quantity surveyors and public works contractors, to whom it will be invaluable.

This edition has not only been revised, but it has been substantially enlarged, in order to incorporate in the book sufficient data to enable structural engineers and draughtsmen to carry out their everyday work without constant reference to many different books. It is a book for the desk rather than the shelf or book-case.

The book opens with a brief outline of the steel plant at Scunthorpe and the method of manufacture of pig iron, steel, plates and sections, and also the qualities of steel supplied. Particulars are then given of plates and sections, and of stanchions and struts in both mild-steel and in high-tensile steel with tables of safe loads and properties of joists and channel stanchions and struts. Notes are given on high-tensile and mild-steel beams, compound girders, gantry girders, plate girders and roof trusses, with tables of safe loads and of deflections for beams and girders. A chapter is devoted to electric welding of structural steelwork incorporating useful data. Particulars are given of Frodingham and other makes of sheet pilings and a chapter deals with reinforced concrete and another on timber. The concluding chapter is concerned with general information, formulæ, tables, etc., and includes standard loading for bridges ; safe pressures on foundations and masonry, floor loads ; various definitions and formulæ ; data for beams and continuous beams under various conditions of loading ; columns with eccentric loads ; properties of various sections ; tables, mathematical formulæ, etc. The book is complete with a 16-page index.

This book, containing over 900 pages, is admirably produced for service and we believe that the demand for copies will far exceed the supply.

Published by Appleby-Frodingham Steel Co. Ltd., Scunthorpe ; copies available from The United Steel Companies Ltd., Westbourne Park, Sheffield, price 21s. net.

Colonial Development Plans

SIDELIGHTS on some of the many plans in preparation for the fuller development of the British Colonies, in order to make their natural resources available to the post-war world, and to improve the standard of life of their peoples, are shown in the annual report of the Imperial Institute, South Kensington, recently issued. References are also made to some Dominion and Indian schemes in prospect.

More intensive geological surveys are contemplated to study geological conditions in the Colonies and to locate further mineral deposits of economic value. The report states that the Committee appointed to give expert advice to the Colonial Secretary on the post-war organisation of Colonial Geological Surveys submitted its views in October.

Comprehensive statements are also being prepared on Colonial building materials of mineral origin for the Colonial Housing Research Group at the Colonial Office. The first of them, dealing with the whole of the West Indies, has already been submitted and the second, on the West African Colonies, is in an advanced stage.

Substantial deposits of lignite, believed to be the first discovery of solid fuel recorded in the Colony, have been found in Sierra Leone. These are comparable with Southern Nigerian lignite in quality, and a recent inquiry at the Institute suggests that their use for brick-making and other local purposes is contemplated. Prospecting is still in progress. Outcrops five miles apart have been located, and in one small area drilling has proved the presence of 100,000 tons of the material. Large samples from two trial workings are being examined at the Institute, and a third from another site is expected.

On the commercial side a firm approached by the Institute is showing an interest in an unusual rock resembling soapstone from Kenya. India's remarkable industrial developments during the war have aroused interest in her natural resources in fuels. A leading metallurgical firm in Britain has been assisted in making a general survey of information concerning the coal-fields of India.

Growing use of bentonite has resulted in inquiries to the Institute about deposits in Canada, New Zealand, Kenya and India, and the uses of the mineral in oil-well drilling, fine chemicals, photography, as a binder in moulding sands, and as a sealing compound for leaking dams. Questions have also been answered concerning the possible use of vermiculite from Empire sources for pre-fabricated building units, and for use in paints, inks, linoleum and in oil-refining. This mineral is now principally employed, according to the latest information from America, as an aggregate for light-weight concrete but considerable amounts are also still used for heat and sound insulation.

The increasing industrial importance of the lesser-known metals and rare earths has stimulated an unusual number of inquiries about their properties, occurrences, uses and marketing. The varieties include : zirconium, selenium, beryllium, thorium, lanthanum, lithium, caesium, uranium, indium, germanium, thallium, rhenium, and gallium. Many of the inquiries relate to electronics and fine chemicals.

Various samples of other ores tested at the Institute came from Travancore, India, Devon and Cornwall,

Palestine, South Africa, Canada, St. Helena and Kenya. Eight samples of tungsten were sent by the Wolfram Board at Jos, Nigeria. Four of them showed on analysis more than 70% of tungstic oxide, two others between 60 and 70%, and the other two about 45%.

Much confidential work has been done by the Institute for some Empire and Allied Governments, but mention is made of an instance in which two senior officers from the Mineral Intelligence Department were lent to carry out an urgent geophysical survey at a Government-operated mine in Britain in order to locate more rapidly the position of orebodies of a strategic mineral.

There is much in this report which will be of interest to readers. By Sir Harry Lindsay, K.C.I.E., C.B.E.; published by the Imperial Institute, South Kensington, London, S.W. 7.

Equilibrium Diagrams of the Systems Copper-Tin, Copper-Zinc, and Copper-Aluminium

THE Institute of Metals has added the above three alloy systems to its Annotated Equilibrium Diagram Service. These are the systems most requested by members when the series was first announced about a year ago. Each of the series consists of (*a*) the diagram reproduced on a generous scale and based on what is regarded as the most reliable work in card-phase yield, (*b*) a table giving all important data connected with the diagram, (*c*) a number of critical notes, and (*d*) a list of references. The first number of the series (the aluminium-zinc system) is still available.

By G. V. Raynor, M.A,. D.Ph. (Institute of Metals Annotated Equilibrium Diagram Series Nos. 2, 3, and 4, respectively), $11\frac{1}{4} \times 8\frac{3}{4}$ in. Pp. 6, with one figure. 1944. London: The Institute of Metals, 4, Grosvenor Gardens, S.W. 1. (6d. each, post free).

1944 Book of A.S.T.M. Standards

THE complete new 1944 Book of A.S.T.M. Standards, issued in three parts contains in their latest approved form all of the Society's widely used specifications and tests for materials. A most important book in connection with the production, purchase and use of materials, the latest edition has 1,235 specifications and standard methods which cover more than 6,000 pages. All specifications, whether formal standards or tentative are given. The book is divided as follows:—

Part I, Metals.—Ferrous and non-ferrous metals (all A and B and some E serial designations) except methods of chemical analysis. General testing methods (E serial designations).

Part II, Non-metallic Materials.—Constructional.—Cementitious materials, concrete and aggregates, masonry building units, ceramics, pipe and tile, thermal insulating materials (all C serial designations). Wood and wood preservatives, paints, varnishes and lacquers, road materials, water-proofing and roofing materials, soils (certain D serial designations). General testing methods, thermometers (E serial designations).

Part III, Non-metallic Materials—General.—Fuels, petroleum products, electrical insulating materials, rubber, textiles, soaps and detergents, paper, plastics, water (remainder of D serial designations). General testing methods, thermometers (E serial designations).

An innovation is the inclusion of all emmergency standards and emergency alternate provisions which have been widely used to expedite production and procurement of important materials. (The Society has issued a separate volume on Chemical Analysis of Metals, including standards and recommendations for both ferrous and non-ferrous metals. These methods are not included in the Book of Standards.)

Each part of the new edition has a complete subject index (from 36 to 44 pages). There are two extensive tables of contents, the first lists all standards under general materials headings; the second according to the serial designations of the standards. These features facilitate reference to any subjects covered.

Some idea of the large increase in the size of books is indicated from comparative figures for 1939, 1942, and 1944. (Publication of the books has been triennial, until this latest edition, a full year ahead of normal issuance because of heavy demands for the 1942 Book, much of it occasioned by the war effort.)

1939—866 STANDARDS—3,700 PAGES.
1942—1,104 STANDARDS*—4,900 PAGES.
1944—1,235 STANDARDS*—6,030 PAGES.

* Not including emergency standards, in 1942, 19; 1944, 25.

Supplements, Detailed Index.—To keep the books up to date, a supplement will be issued to *each* part late in 1945. As a service with the 1944 Book of Standards there is a complete 200–page Index to Standards, which is furnished without additional charge and a copy accompanies the purchase of each part or complete set.

This publication is a most extensive one and will undoubtedly be of great interest to many of our readers.

Published by the American Society for Testing Materials, 250, South Broad Street, Philadelphia 2, Pa., U.S.A. Price $10 each part; Supplements $4 for each part, each year. Note: For half-leather binding the charge is $1 extra for each part and each Supplement part.

The Nickel Bulletin

THE Nickel Bulletin for March contains abstracts dealing with the electrodeposition of silver, the relationship between yield stress and machinability, stress-corrosion cracking and soil corrosion.

Copies of the Bulletin may be obtained, free of charge, from the Mond Nickel Co., Ltd., Grosvenor House, Park Lane, London, W.1. Individuals are requested to give the name of the firm with whom they are employed or some other indication of their special interest.

Personal

MR. W. B. Pickering, commercial manager and Director of Hadfields, Ltd., Sheffield, has retired after a period of service with the Company extending over 53 years.

Mr. H. Humphries, late Director of Steel Castings and Forgings of the Ministry of Supply (Iron and Steel Control), has been appointed successor to Mr. Pickering as commercial manager. He has also been made a local director of the company.

Mr. T. J. Tait has relinguished the position of secretary to Thomas Bolton & Sons, Ltd., and, from March 31, 1945, has been appointed a director of the Company. The former assistant secretary, Mr. J. A. Foulds, A.C.A., has succeeded Mr. Tait as secretary.

The Yielding Phenomenon of Metals

Influence of Speed and Loading Conditions

Part IV

By Georges Welter

Professor of Applied Mechanics, Ecole Polytechnique, Montreal.

The yielding phenomenon of metals, of importance in applied mechanics as well as in metallurgy, is not yet sufficiently understood. Besides a theoretical consideration, the various factors which have a pronounced influence on the yielding of metals such as the kind of testing machine with its load-indicating device, as well as the rate of plastic deformation of the specimen, have been investigated. In order to obtain additional results about the loading conditions of the specimen, a new direct loading machine with a special recorder was designed, and the stress-strain diagrams of this machine were compared to those of the rigid straining machine. Furthermore, the transmission of the loads from the machine into the test specimen without harmful secondary effects was studied by means of three types of newly developed universal joints which allow loading the specimen axially.

In order to understand the whole stress-strain diagram, an automatic time chronograph was designed.

Furthermore, the characteristics of the two types of machine, the rigid straining machine and the direct loading machine, were compared to each other during the static loading tests, as well as during the dynamic tests with the machine in normal operation. During these tests an artificial yielding effect was obtained by a relative displacement of the loading faces of the machines. Stress-strain diagrams were recorded under different loading conditions; diagrams showing a most characteristic difference between these two types of machines were obtained.

By means of a special device based on sliding friction between three plates screwed together, the dynamic behaviour during yielding of metals in both types of testing machines was analysed and interesting diagrams were recorded. The rigidity of the straining machine could be gradually decreased by inserting elastically stressed elements between the grips and the frame of the machine. In five different steps the characteristics of the rigid straining machine were gradually made nearly equal to those of the direct loading machine.

Comparative tests with usual extensometers measuring in different places the relative movements of the grips and the loading faces of the machine gave valuable indications about the reliability of these instruments.

The upper and lower yield-points of mild steel were studied in function of the speed between about 400 lb. and 20,000 lb. per min. These tests show that the lower yield-point is much more affected by high deformation speed than the upper yield-point.

Time-controlled stress-strain diagrams show in all loading phases important variations of the loading speed in the rigid straining machine and the straining speed in the direct loading machine. The difference between the two types of machines becomes especially effective by comparing the stress-strain diagram of duralumin test specimens tested shortly after quenching and showing a very characteristic yielding effect.

The diagram No. 1 shown in Fig. 47, was obtained with the usual recorder measuring the displacement of the cross-heads of the machine by means of small pulleys attached at the loading tables and a cord connected with the drum of the recorder on which the load is registered simultaneously. In order to control the above results, shown in Fig. 47, a second test was made with the sliding device used under similar conditions, only a more precise recorder was used. The electrical recorder, Fig. 8, and described in B-(a), was adjusted between the loading tables of the machine; the magnification of the displacement of the cross-heads of the machine is about 2·5 times that given by the recorder used for the diagram in Fig. 47.

As may be seen in Fig. 48, this diagram is very similar to that of Fig. 47; only the loads are somewhat different and the scale for the elongation is about 2·5 times greater due to the more precise electrical apparatus. Here again we see the three principal phases of the stress-strain diagram of mild steel as: A–B representing the elastic phase, the phase B–C a dropping of the load from 1,500 lb. to about 950 lb. is recorded as well as a continuous yielding in smaller steps with a series of maximum and minimum loads D, E, F, G, H, I up to the last slipping X–Y. Beginning at this point the load again starts to rise continuously according to Y–Z. The number of sliding steps is about 39 for a whole free sliding

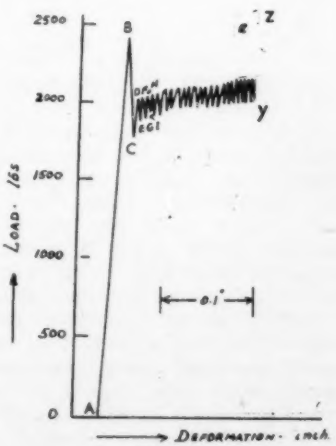


Fig. 47

distance of about $\frac{210}{1000}$ in., so that each step represents an average slipping in the device of about $\frac{5}{1000}$ in. to $\frac{8}{1000}$ in.

In order to get more reliable information concerning the most important and characteristic phase of the yielding phenomenon itself, that of the peculiar dropping of the load from a higher to a lower value, a diagram was made with the sliding device recording simultaneously the time by the autographic chronometer described in B–(e). In Fig. 49 are represented two diagrams: the load-deformation diagram similar to diagram 47 recorded with the sliding device and an autographic time diagram recorded simultaneously with the main stress-strain diagram. The load was increased at a rate of about 20 lb. per sec. or 1,200 lb. per min., and the time elapsed between two adjacent points in part a–b of the diagram was of the order of 1 sec. Much faster, however, was on the other hand the decrease of the load in the first yielding period b–c. For the total drop of the load from *b* to *c* a drop of nearly 450 lb., it took only about 2 secs. (these points between b–c, Fig. 49, are marked with a circle). This means that the load dropped in this period at a speed about ten times as fast (200 lb. per sec.) as the rate in the loading period a–b (20 lb. per sec.). Whenever this drop of the load is fairly fast, the exact time elapsed during the momentaneous sharp sliding process in the device is difficult to estimate. The slip itself takes place, as estimated by direct observation and by the sharp audible crack in the device, in a much shorter time than $\frac{1}{10}$ of a sec. The machine with its recording device indicates this effect lasting at least twenty times, if not fifty times longer; this effect is naturally due, as already mentioned, to the inertia of the machine and the individual parts of the recorder.

As this diagram A–B–C was recorded on the running machine, in point *C* after the minimum load is attained, the load again rises automatically (C–D) at about the same rate (25 lb. per sec.) as for the phase A–B. At a load of 1,440 lb. the sliding, accompanied this time by a drop of 360 lb. from *D* to *E*, takes place again in somewhat less than 2 secs. (d–e) or at a rate of the decreasing load of about 200 lb. per second. After this sudden yielding, the load starts to increase again from *E* to *F* and the same process, followed by the rapid load decrease, takes place regularly each time with about the same results until the free sliding space of the device is exhausted. In this diagram are shown only the first four slips (1) followed by six further slips (2), diagram 49; these records have been separated from the first group (1) in order to be able to have a clear picture of the time record of the second group (2) interfering otherwise with the stress-strain diagram of the first group. By this test, analysing accurately the speed of the load decrease and the time of the drop of the load from a higher to a lower value with the machine in operation, it becomes clear that the recorded diagrams in the dropping phase are not at all in accordance with the real speed of sliding which provokes the sudden, strange decrease of the loaded specimen in the rigid straining machine. It seems that this drop has nothing to do with any sliding characteristics of the test specimen, but is merely related to the testing machines.

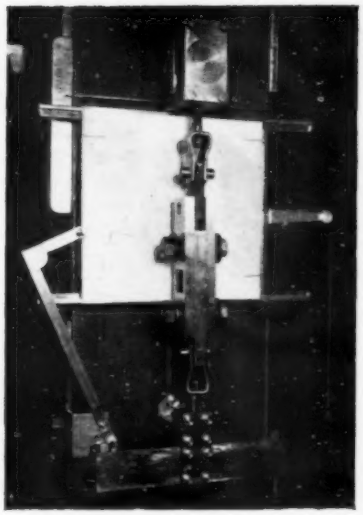


Fig. 50

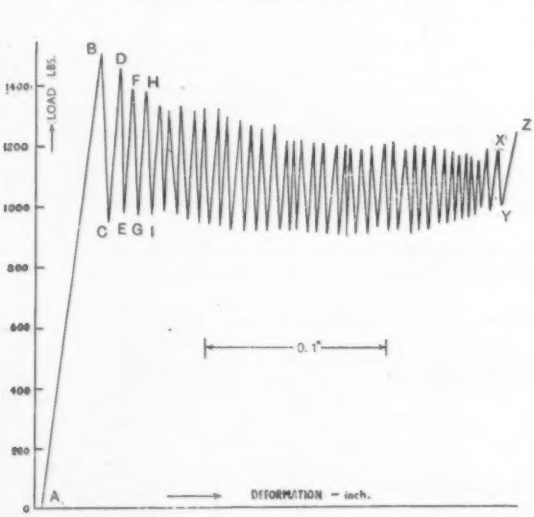


Fig. 48

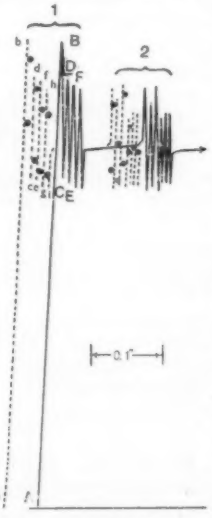


Fig. 49

D–(b)–(2) *Direct loading machine.*— It may be interesting to note that a completely different picture of this same phenomenon, executed with the same sliding device, is obtained on the direct loading machine. If this device is attached between the grips of the machine, as shown in Fig. 50, the diagram recorded is so different from that of the rigid straining machine, that, beginning at the first sliding up to the further increasing of the load after the total yielding process, it is not in any way alike to the characteristic slip diagrams of Fig. 47 to 49. As may be seen the upper and lower yield values are not recorded, no partial slipping in smaller steps of a few thousandths of an inch takes place, in other words, no repetition of the process with the machine in operation can be observed. Furthermore with the direct loading machine the complete phenomenon of sliding takes place in an excessively short time.

Results of this kind of test are shown in Fig. 51. After the elastic deformation A–B, the sliding takes place suddenly in *B* (Fig. 51, diagram No. 1). Due to the direct load applied to the device and contrary to the rigid straining machine, sliding does not take place in small steps. One single

extremely rapid sliding along the available length of the device, produces the nearly horizontal part B–C of the diagram. The whole irregular, often interrupted and complicated process of the straining machine, is extremely simplified in the direct loading machine. All that is perceptible of this phenomenon is a sudden crack and instantaneously the part B–C appears in the diagram. From *C* to *D* the load increases again regularly independently of the machine

Fig. 51

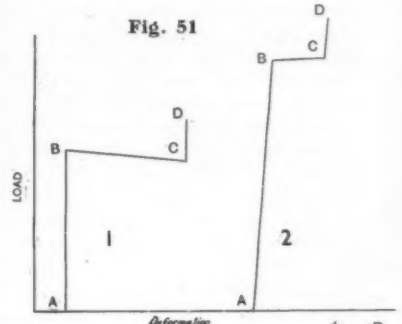
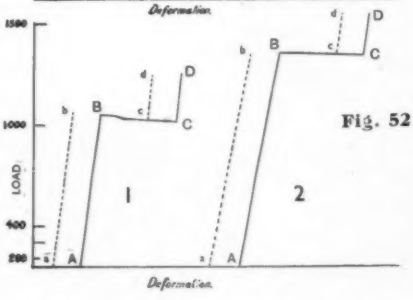


Fig. 52



used for the test. If the load at which sliding takes place is low, part B–C of the diagram of the direct loading machine decreases somewhat from B–C, as the sliding elongation of the device causes a small drop of the load (compare Fig. 39). At higher loads, however, and smaller displacements of the cross-heads, the drop of the load is nearly negligible, as shown in diagram No. 2, Fig. 51.

Furthermore, to get more reliable results concerning the time control during this, as it seems a kind of catastrophic change in the stress-strain equilibrium of the machine, some tests with the autographic time recorder were made. Diagram No. 1 of Fig. 52 shows one of these tests in which sliding took place at a load of about 1,000 lb.; No. 2 represents a similar diagram: here slipping occurs at higher loads (about 1,400 lb.). It is interesting to note that after initial loading A–B was accomplished at a rate of about 1,500 lb. per min., sliding in *B* took place so suddenly that the whole process was accomplished in less than 1 sec. (b–c) and it can be estimated that it will be of the order of less than about $\frac{1}{10}$ of a sec. There is no time-mark printed by the recorder between the beginning (b) and the end (c) of the total sliding process. After this sudden change, the load increases again slowly along C–D and this at about the same rate as for the elastic period A–B.

Comparing with the sliding process

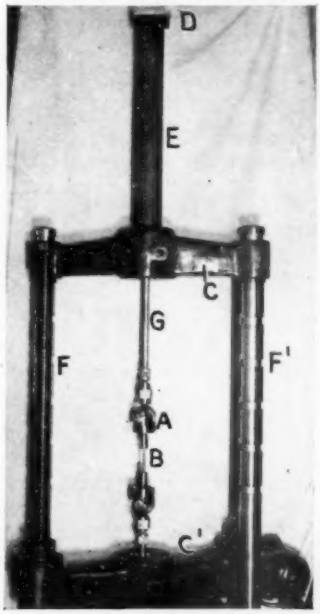


Fig. 53

in the rigid straining machine, it is of interest to note that for a very small sliding of a few thousandths of an inch, this machine needs about 2 secs. for the load to fall to a lower value and the whole process lasts several minutes to pass through the whole dispensible length in numerous small steps. In the direct loading machine, however, a completely different phenomenon takes place. In less than 1 sec. the whole available free length of the sliding device is absorbed, and this in one single step without any appreciable drop of the load. This represents a deformation speed during yielding which is a few hundred times and even over a thousand times faster than the one observed in the rigid straining machine. Diagram No. 2, Fig. 52 represents a similar timely-controlled test where the sliding took place at higher loads (about 1,400 lb.). Here also the characteristic fact can be observed that no time-mark which takes place regularly every second, was recorded in the yielding period between the points *b* and *c*. The whole sliding process B–C was accomplished in a fraction of a second only.

This test confirms clearly what has been already stated in the theoretical considerations at the beginning of this work (A–b–1): yielding is characterised by a horizontal line in the stress-strain diagram recorded by the direct loading machine.

Furthermore, the characteristics recorded in the direct loading machine during yielding seem to conform more to the real loading conditions encountered in practice. Numerous elements of construction are stressed in practice by direct loading acting freely on these elements without any limitation of straining. This is, for instance, the case for cables, chains, haulage ropes, rods of suspension-bridges, beams under flexion forces, elements for the transmission of power, as piston rods, connecting rods, etc. All these elements can freely yield under the applied stresses without any diminution of the load after a small initial deformation occurs, as is the case for the test specimen in the rigid straining machine.

E—VARIATION OF STIFFNESS OF THE RIGID STRAINING MACHINE

As shown in the preceding part D, there exists a fundamental difference in the behaviour of rigid straining machines and direct loading machines concerning the sudden yielding of the test specimen. With regard to this fact it was tried by the following series of tests to remove the undesirable characteristics of the rigid straining machine. This machine provokes the yielding of the material in different phases by showing a sudden appreciable drop of the applied load followed by irregular steps of stress and strain in the lower yielding period. It seemed desirable to reduce gradually the initial maximum rigidity of the straining machine employed for these tests with the aim of bringing the characteristics of this machine step by step nearer to those of the direct loading machine. So it would be possible to bridge over the wide gap existing between these two machines, the direct loading machine and the rigid straining machine, two antipodes in the materials testing practice.

(a) Elastic bar and beam with slipping device and electrical extensometer between loading tables

In order to reduce the extreme

rigidity of the Baldwin machine, the first step consisted into inserting an elastic element between the loading grips and the frame of the machine. For this purpose a first slight reduction of the rigidity of the machine was obtained by elastic deformation of a highly resistant aluminium-alloy bar under tensile loads. As shown in Fig. 53, the upper grip *A* (universal joint) of the test specimen *B* was not attached as usually at the upper cross-head *C* of the machine, but by means of a duralumin bar *G* about 60 in. long and 1 in. in diameter, the specimen was fixed at a point *D* far above the frame of the machine and supported by a steel tube *E* resting on the cross-head *C* of the machine. The very rigid frame of the machine consisting of the cross-pieces C–C′ and the columns F–F′, was in this way transformed into an appreciably less rigid machine due to the additional elastic longitudinal elongation of the duralumin bar and the steel tube. It is

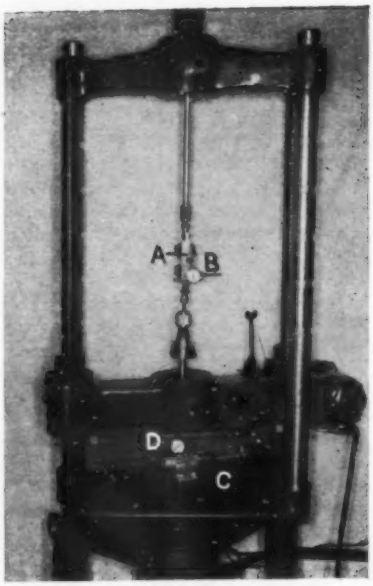


Fig. 54

evident that the stress-strain diagrams recorded with the machine transformed in this way must be different from those of the rigid machine. In order to determine how far this elastic suspension of the specimen influences the shape of the diagram, the sliding device used in the previous tests was adjusted in the machine, as shown in *A*, Fig. 54. A dial micrometer *B* was fixed to the device *A* to measure the amount of sliding directly between the platens at each loading step. As for the control tests of the rigid machine, according to Fig. 48, the diagram was this time recorded with the electrical compressometer shown in Fig. 8. This instrument was placed, as can be seen in *C*, Fig. 54, between the loading tables of the machine. The relative movement of these tables was also measured by a dial micrometer *D*.

Fig. 55 shows the diagram obtained with the machine in operation fitted with this new, more elastic suspension of the test specimen. After an initial maximum load *B* of about 2,370 lb., the first drop of the load takes place, falling down to about 750 lb. The most striking fact is the appreciably reduced steps of the drop of the load, as compared to identical results obtained on the rigid machine (Fig. 48). In only about 21 steps the total available free slipping length was exhausted compared to about the twice as many steps (38) of the rigid machine. Also the slope of this diagram representing the elastic modulus of the machine is greater than for the stiffer machine without any intermediate elastic members.

Further diagrams recorded on the Baldwin machine with yet more elastic suspension conditions are shown in Fig. 56. Besides the duralumin bar attached to the upper grip, a double beam E–E′ composed of two *I* profiles No. 4 was fixed in the middle to the lower grip by a short steel bar and supported on both ends at the lower cross-head *F* of the machine, Fig. 54. In this way the elasticity of the machine was greatly improved. This is also clearly shown in the diagrams of Fig. 56. Two diagrams A–B–C–D–E and A′–B′–C′–D′ were recorded under low and high sliding loads, easy to obtain by tightening more or less the transverse bolts of the sliding device. These diagrams show not only a yet greater slope than the preceding one, Fig. 55, but the different sliding steps are less numerous and much more pronounced. Even at the lower loads between 800 lb. and about 400 lb. there is only a total of about 17 sliding steps and at the loads between 1,600 lb. and 700 lb. only 8½ steps were recorded for the whole free length of the device. This is only about one quarter of the steps recorded in the rigid machine. It becomes evident that due to the springiness of the machine provided with the duralumin bar and the transverse beams, a completely different diagram from that of the rigid machine is recorded under

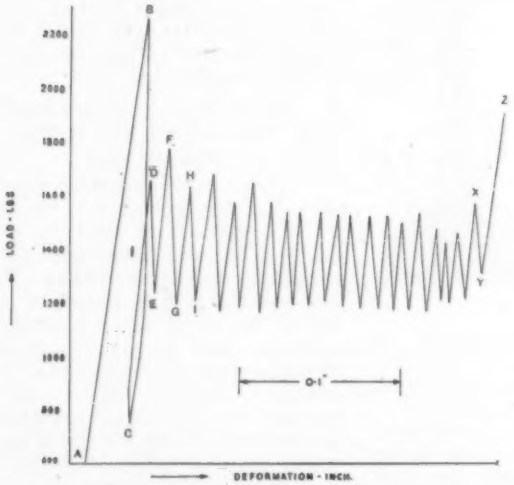


Fig. 55

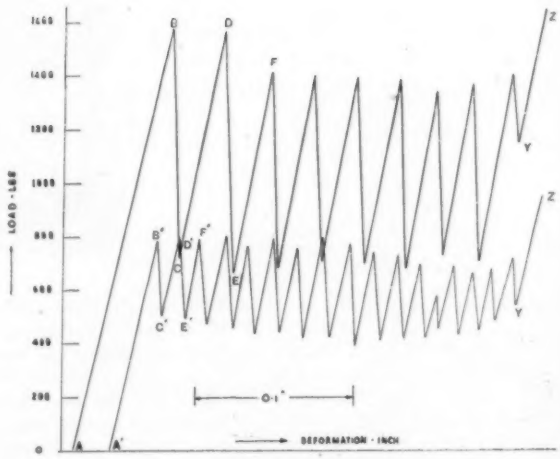


Fig. 56

quite identical testing conditions. In the elastic machine the load falls for each sliding of about 700 lb. to 800 lb. in a few steps only while in the rigid machine the drop of the load is each time about half of these values and the number of steps is about four times as great. The rigid machine provokes a sliding of only about $\frac{1}{1000}$ in. for each step compared to slips about five times as great in the elastic machine and under the same loading conditions.

Another interesting fact can be deducted from these diagrams. As the electrical compressometer recording the deflection of the machine was placed between the loading tables, it is clear that the movements of these two points, due to the massive frame of the machine, correspond to the gripping points of the rigid machine. In the present case, however, the elasticity of the machine being appreciably increased, the slope of the loading phase in function of the elasticity of the machine is clearly pronounced (see slope A–B and A′–B′ of diagrams 55 and 56 compared to Fig. 48). On the other hand the sliding period itself (B–C, D–E or B′–C′, D′–E′) during which an effective displacement of the grips takes place, is not visible in this diagram, independently if the machine is elastic or rigid. This means that the effective sliding in the device increasing the length between the grips of the machine is not directly recorded in the diagram but is nearly completely absorbed by the elasticity of the soft or springing machines as well as the rigid machines.

(b) Helical springs with slipping device

(1) *Electrical and cord extensometers between loading tables.*—Another more important step to obtain higher elasticity or greater springiness of the Baldwin machine was made by using for this experiment two helical springs in compression (of 2,400 lb. per in.) placed under the lower cross-head of the machine, instead of the elastic deformation of a duralumin bar and a simple beam with load at centre. These springs working in parallel were connected by a steel bar with the lower grip of the slipping device, as shown in Fig. 57. This time the great rigidity of the machine had completely disappeared and a quite different diagram represented in Fig. 58 was recorded. The slope of the load increase is in this case extremely high (about 30° instead of about 80° for the rigid machine) and at a load of about 800 lb. the nearly total available sliding length was instantaneously exhausted accompanied by a very sharp crack of the sliding plates while the load fell down to only 120 lb. Curiously, this sliding of the device by about 0·2 in. is not all recorded by the machine at the same moment; it is merely indicated by the dropping of the load which annihilates the elastic compression forces of the springs by the load falling down to a very low limit.

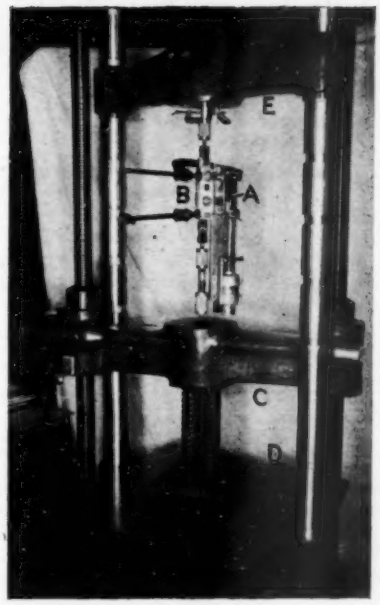


Fig. 57

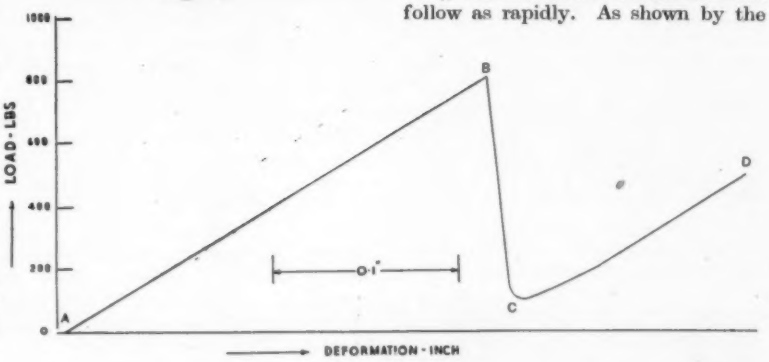


Fig. 58

A second test made under the same conditions gives exactly the same results concerning the stress-strain diagram, the drop of the load and the lack of the sliding length in the diagram.

It can be said that this appreciable instantaneous sliding of the device is absorbed nearly completely by the helical springs without leaving a very perceptible trace in the horizontal direction of the diagram which is supposed to record the length increase between the grips. This seems to be an interesting fact especially in combination with a clear understanding of the yielding process of mild steel in hard or soft straining machines.

In order to be quite sure of these results, the tests with two springs in parallel were repeated with the ordinary roller extensometer placed on the loading cross-heads of the machine producing the operation of the drum by a cord. This test set up is shown in Fig. 57 and the diagram was made simultaneously with the autographic time recorder. Fig. 59 shows the results accompanied by the time records. The slope of this diagram is smaller than the one obtained with the electrical extensometer having a 2·5 greater magnification. Here also at a given load *B* (1,060 lb.) attained at a rate of about 1,500 lb. per min., the total sliding B–C takes place instantaneously (in less than about $\frac{1}{10}$ of a sec.), but the load indicator does not follow as rapidly. As shown by the points l–m–n–o–p–q–r–s–t, representing one second interval, the time necessary for the load recording device to fall down to 220 lb. from *B* to *C* is about 9 to 10 secs., starting with a somewhat greater dropping speed. After the complete sliding B–C, recorded exclusively by the drop of the load of 830 lb., the load continues again to increase regularly along C–D (diagram No. 1, Fig. 59).

For this test a check made under slower loading rates of about only 600 lb. per min. gives exactly the same results concerning the dropping speed from a higher to a lower load, diagram No. 2, Fig. 59.

F—EXTENSOMETERS ADJUSTED ON TEST SPECIMENS

As already shown in the preceding part E–(a) the effective increase of the

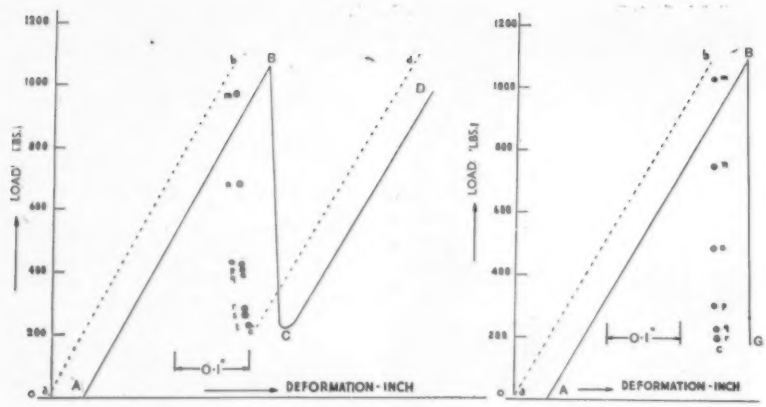


Fig. 59

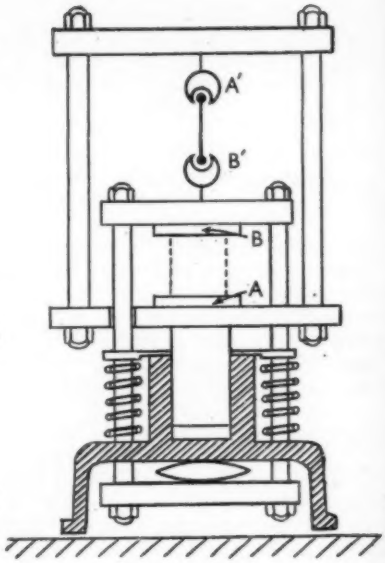


Fig. 59a

length between the grips of the rigid machine as well as the elastic machine is not directly recorded in the diagram but is nearly completely absorbed by the elastic deformation of the machine itself. Therefore it is not the same if the recorder is fixed between the loading tables of the rigid straining machine in points *A* and *B* according to Fig. 59a or on the test specimen itself, that is between the loading points of the grip in *A'* and *B'* (Fig. 59a). In order to obtain more information about the sliding process, the electrical recorder *A* was fixed directly on the sliding device itself *B*, as shown in Fig. 57 and not between the loading tables C–D. This is, as will be shown, of a principal influence on the stress-strain diagram recorded.

(a) Rigid machine

(1) *Electrical Extensometer.*—Using the electrical extensometer the rigid Baldwin machine was again loaded without any modification; the grips were fixed rigidly on the loading cross-heads C–E and the diagram was recorded on the machine in operation. Simultaneously the time of testing was recorded. The results as represented in Fig. 61, show clearly what happens between the grips during sliding. Due to the rigidity of the machine, the sliding takes place in relative small steps at loads between 1,900 lb. and 1,500 lb. The loading rate between A–B was of about 40 lb. per sec. As the sliding device remains without elastic deformation during loading, the diagram is without slope in part A–B and at the first slip from *B* to *C* the load falls down in the rigid machine by about 300 lb. in this loading range. Furthermore, the extensometer being fixed on the sliding device itself, the slip for each step is recorded by a horizontal displacement of the pointer in the diagram. The load falling simultaneously fairly slowly, the phase B–C is recorded. The time necessary for this operation in the diagram is somewhat more than 1 sec. The encircled points m–n–o, etc., represent the time recorded between *B* and *C*, D and E, etc., each point being distant from one another by 1 sec. By this means we are enabled to have a clear representation of the single sliding phases. The magnification (×1,000) of the electrical extensometer was chosen at its maximum which means a four-time higher magnification as for the preceding tests having a magnification of 250. The number of steps was, as for the previous tests, about 28 (not all represented in this diagram) for the whole sliding length; at each step the load fell down in about more than

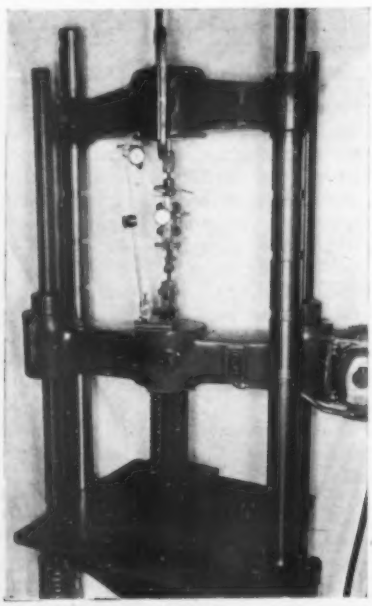


Fig. 60

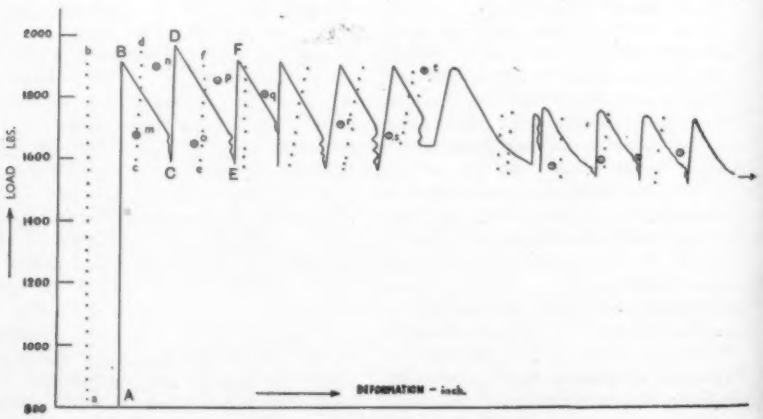


Fig. 61

1 sec. (points m–n–o). Regarding the fact that the sliding in the device is for each step instantaneously accomplished, the diagram responding to the real behaviour of the machine ought to be A–B–D–C–D–F–E if the elongation could be recorded as fast as the sliding process takes place. We have, however, already seen that also the drop of the load is delayed in this machine, following only fairly slowly the real effective slip of the device.

Galling and Seizing

A study of friction galling and seizing of metal surfaces sliding in contact one with another was published by the Meehanite Research Institute of America, Inc., New Rochella, New York ; this abstract of the work is by courtesy of the Research Department, Diamond Trading Co. Ltd.

FOR the tests a two-gauge dynamometer designed by H. Ernst of the Cincinnati Milling Machine Company was mounted on the table of a vertical milling machine (Fig. 1). The rotating test member B, a cylinder of $\frac{7}{8}$ in. outer and $\frac{1}{2}$ in. internal diameter, is attached to the spindle of the milling machine and is bearing against the stationary test member A, which is mounted in the dynamometer cup. The desired bearing pressure is obtained by using the knee of the milling machine. The resulting friction torque at any moment during the test can be read from a torque pressure gauge actuated by sylphon bellows. The applied load is indicated by a load gauge. The point of initial galling of the contacting surfaces is denoted by a sudden increase in friction torque.

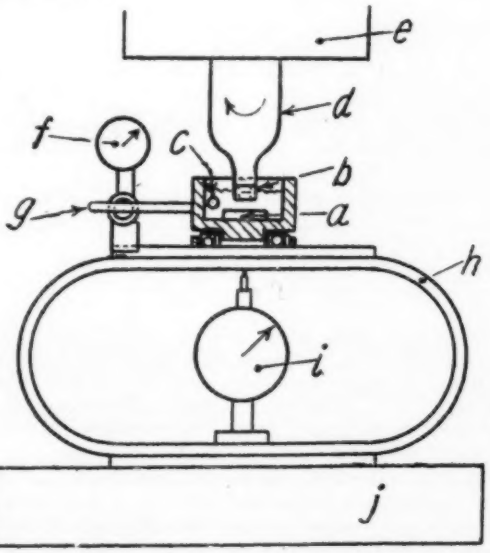


Fig. 1.—Apparatus for measuring bearing qualities of metal, according to H. Ernst.

(*a*) Stationary test member.
(*b*) Rotating test member.
(*c*) Oil.
(*d*) Spindle.
(*e*) Milling machine.
(*d*) Spindle.
(*e*) Milling machine.
(*f*) Torque pressure gauge.
(*g*) Sylphon bellows.
(*h*) Proving ring.
(*i*) Load gauge.
(*j*) Milling machine table.

In the tests various combinations of materials were used, including graphite cast iron, various types of Meehanite, bronze, and steel. The physical characteristics of the materials were measured and the relative soothness of the surfaces determined in r.m.s. values by means of a Brush surface analyser before and after testing.

The " wearing " of " as-machined " making bearings is always accompanied by a change in surface geometry. If steel is used as the rotating member in combination with bronze or Meehanite it shows the greater change. The Meehanite surface shows only some smoothing of the tops of the machining marks. Thus a " as machined" steel surface of 60 micro-in. r.m.s. is worn in to a surface of 7 micro-in., whereas the original " as machined " surface of the Meehanite bearing is worn down at the same time from 80–60 micro-in.

Fig. 2 shows graphically the progressive development by intermittent loading and its effect on the frictional coefficient and the galling resistance. By effecting a drop

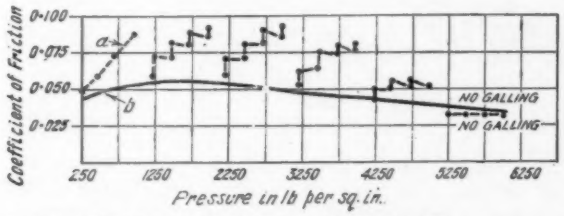


Fig. 2.—Steel run against type G A Meehanite.

(*a*) " As machined " surfaces loaded at 250 lb./sq. in. per min. with the introduction of rest periods after every four 250 lb./sq. in. load increment increases.
(*b*) Samples re-run (now considered " worn-in "), but with the elimination of the rest periods.

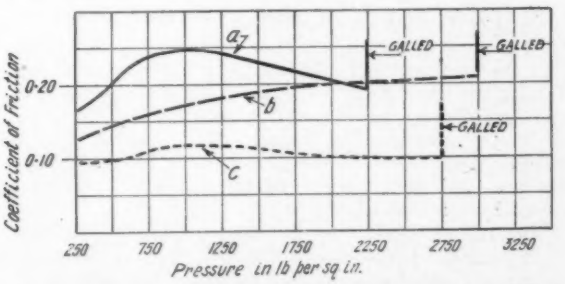


Fig. 3.—Effect of pressure on the coefficient of friction of " as-machined " surfaces under continuous loading conditions.

(*a*) Steel against bronze.
(*b*) steel against G A Meehanite.
(*c*) G A Meehanite against G A Meehanite.

in temperature at the contracting surfaces after some definite loading interval the steadily increasing coefficient of friction is retarded before galling can ensue. At the higher loads the coefficient of friction becomes progressively lower as the making metal surfaces are

Bulletin No. 17, Meehanite Research Institute.

GALLING PRESSURES FOR VARIOUS METAL COMBINATIONS

Metal Combinations [1]	Surface Smoothness r.m.s. micro-in.	Pressure of initial galling lb./sq. in.	Average Coefficient of frictilon
Steel and	60	[2] Less than 2,000	0·22
Bronze	40		
Steel and	60	2,750	0·16
Graphitic Cast Iron	160		
Steel and	60	3,500	0·16
G E Meehanite	125		
Steel and	60	3,000	0·16
G A Meehanite	70		
G A Meehanite and	65	2,750	0·11
G A Meehanite	75		

[1] In " as machined " condition.
[2] Considerable wear noted at this point indicating initial breakdown had occurred at some lower pressure.

" worn-in " and eventually the surfaces run together with a gradual lowering of the coefficient of friction and without any scuffing, galling or seizing.

If no care is taken to permit correct " break-in," galling usually occurs at a relatively low pressure (Fig. 3) and Table I. The speed for these tests was 31 r.p.m., and the load was increased by 250 lb./sq. in. every minute until galling occurred. The steel bronze combination developed a higher friction (average 0·22) than the steel-Meehanite (average 0·16), and the steel-graphite cast iron (average 0·16) combinations, while the steel-Meehanite combination developed a higher friction than the Meehanite-Meehanite combination (average 0·11). The galling pressures for the different combinations, varying from 2,000–3,500 lb./sq. in. is shown in Table I.

Interesting curves were obtained when previously worn-in steel test members were running against " as machined " bronze, graphite, cast iron and Meehanite with load continuously from 250–6,000 lb./sq. in. (Fig. 4). Galling and seizing occurred with the steel-bronze combination at 2,500 lb./sq. in., while the other combinations showed decreasing friction with increasing pressure.

Among the conclusions reached the following seem of importance. The coefficient of friction is not of first importance as far as scuffing, seizing and wear of moving metal parts are concerned.

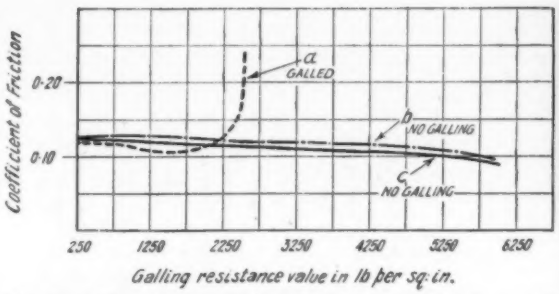


Fig. 4.—Effect of pressure on different combinations—all under continuous loading conditions.
(*a*) " Conditioned " steel against " conditioned " bronze: galled.
(*b*) " Conditioned " steel against " as machined " Graphitic Cast Iron: no galling.
(*c*) " Conditioned " steel against " as machined " G A Meehanite: no galling.

The idea of two dissimilar metals being essential for bearing surfaces lacks scientific evidence.

The chief causes of metal pick up, galling and seizing are :

(*a*) Incorrect structural constitution of the metals employed. (*b*) Rough or inaccurate machining. (*c*) Improper selection of surface finishes. (*d*) Inadequate clearances. (*e*) Overload such as caused by poor alignment. (*f*) Faulty lubrication. (*g*) Uncontrolled temperature conditions. (*h*) Careless " running-in."

Of importance is the correct selection of surface finishes, for instance 8 micro-in. r.m.s. for the moving parts and " as machined " finish for the making members (piston ring and liner) ; steel shaft and bearing ; slide and machine way).

Steel should be " worn-in " (cold worked) before placing in service under full load.

Steel bronze combinations exhibit less resistance to scuffing, galling and wear than steel-Meehanite or Meehanite-Meehanite combinations.

Care is necessary during the " break-in " period.

The choice of lubricant must be given proper consideration.

Magnesium Founding Comes of Age

THE turn of the year marked the coming of age of the magnesium industry in Great Britain. In 1924, after two years of experimental work on the " Elektron " (magnesium) alloys, then in an early stage of development, Sterling Metals, Ltd., entered into an agreement with F. A. Hughes & Co. Ltd. to undertake the practical development of the patented processes owned by that company.

The earlier years of the venture were naturally characterised by the customary admixture of struggle, success and disappointment inevitably encountered in the evolution of a new industry. The progress made, however, will be realised by the fact that in 1936, industry was absorbing castings in the new materials to an amount upwards of 400 tons per annum—no mean achievement considering the usual wariness of designers and engineers in adopting new materials of construction.

The growth of Sterling's output shows the part played in the war effort by the rapidly developing industry. Production rose from the 400 tons of 1936 to a figure well in excess of 3,000 tons in 1944, and this figure excludes an annual production of some 7,000 tons of incendiary bombs. The magnitude of the effort involved is illustrated by the fact that, owing to the low specific gravity of the " Elektron " alloys, 800 tons of metal produced 2¼ million gravity die castings of various weights and types.

This expansion has, naturally, during the past five years been absorbed into the war effort, and has been directed largely into transport fields, on land, at sea and in the air. At the same time, the advantages of ultra-light-weight metallic materials have been appreciated and utilised in all branches of engineering and scientific development.

Sterling's achievement in developing the uses of magnesium (" Elektron ")—which will undoubtedly be a key source of material supply in the future—is one of which British industry can be proud. The development is the more important from a national point of view in that the processes now evolved and used by the chief magnesium metal producers can be maintained on an economic basis entirely by British raw materials and power.

THE general progress of the new Microchemistry Group of the Society of Public Analysts must certainly be viewed with a conisderable amount of approval by all microchemists in this country. On various occasions in these columns we have pointed out that whatever body emerged to represent organised microchemistry here must take full account of the claims of scientists in the provinces. It is eminently satisfying to note that, in the future which is now taking shape, such will be the case. The news that the next meeting of the Group is to take place in Manchester in May indicates the first step in this direction, and it is followed by the even better news that arrangements are already on foot to prepare for further meetings in provincial centres. In other words, the right of microchemists throughout the country to be taken as seriously as those in and around London is adequately realised. Further ground for congratulation is to be found in the fact that the Group, in formulating its constitution, has favoured the election of office-bearers by postal ballot, another desideratum which has been urged in these columns. For a national body to hold its elections at a meeting, no matter in what part of the country the meeting took place, would have been an intolerable restriction on the opportunity of the members to express freely their will in the matter of who should guide activities. The Group has evidently realised this, and has taken the obvious way of ensuring democracy in its organisation. Although the activities of the Group are still of necessity restricted, we may look forward confidently, from these foretastes, to a highly beneficial expansion following on the final cessation of the war in Europe.

Qualitative Inorganic Microanalysis Without Hydrogen Sulphide—Part I.

By R. Belcher and F. Burton

A scheme is described which can be used for the detection of the common metallic ions on the micro scale. Sulphuretted hydrogen is not used as a reagent. The advantages and disadvantages of the scheme are discussed.

SEVERAL schemes which eliminate the use of hydrogen sulphide have been proposed for qualitative inorganic analysis, but none has succeeded in superseding the established scheme. The reasons for their non-adoption are not hard to find. The necessary regrouping of the metals may introduce disadvantages which outweigh the advantage of eliminating hydrogen sulphide. Again, a scheme which works satisfactorily in the hands of a skilled chemist will behave very differently in those of an elementary student. As any teacher of chemistry knows to his sorrow, a raw student using the conventional scheme can produce precipitates in almost every group, even though only one metal may be present. Hence, the only method of obtaining a true assessment of the value of any new scheme is to observe its behaviour when used by elementary students. Since a course in qualitative analysis is usually followed by an examination, most teachers hesitate to adopt a new scheme in case—its demerits proving manifold—it has to be replaced by the conventional scheme part-way through a course. Furthermore, a new scheme should be applied to an extensive range of mixtures before it can be considered thoroughly trustworthy. Certain combinations of particular ions may behave anomalously and this behaviour may only be revealed when that particular combination is subjected to test. Even the conventional scheme, with over half a century's usage behind it, affords such an example only discovered in recent years.[1] Finally, it must be borne in mind that ultimately any scheme must include the less common metals. The established method already provides a basis for their analysis, whereas any new scheme which utilises new group reagents and different groupings for the metals, would require an extensive investigation to determine its utility in this field.

In qualitative inorganic microanalysis the offensive smell of hydrogen sulphide is reduced considerably, because of the small amounts involved. Nevertheless, the elimination of this reagent—other things being equal—would constitute a marked advance. We considered the scheme described by A. J. Mee[2] to appear promising and with certain modifications have adapted

1 Bradbury and Edwards. *J.S.C.I.*, 1940, **59**, 96.
2 "A New Scheme of Elementary Qualitative Analysis," by A. J. Mee. Dent and Sons, 1942.

it to the micro-scale. Although the modified scheme is an improvement on the original, after lengthy trials we have come to the conclusion that the elimination of hydrogen sulphide does not offset other disadvantages which are inherent in the scheme. Although in the hands of an experienced worker the results leave nothing to be desired, more care is required in applying and interpreting the tests than in the conventional scheme. We have tested a fairly wide range of representative mixtures but it is obviously impossible for every combination to be examined. No attempt has been made to study its application to the analysis of the so-called rarer elements.

Besides eliminating hydrogen sulphide, Mee breaks from traditional practice in elementary analysis by applying specific and selective tests in certain cases without conducting a separation. We have followed Mee in this respect, except that in some cases alternative reagents have been adopted, since we preferred them. This procedure is regarded unfavourably by many teachers, since it is often claimed that the educational value derived from separating every metal is lost. It appears to us that, in terms of utility, the method of applying a specific test for a certain metal in the presence of other metals associated with it in its group, is at least as equally informative as that of separating each individual prior to applying its confirmatory test. Those who prefer to separate each metal can easily modify existing methods and incorporate them in the following schemes.

Basic Separation Scheme

Mee's scheme can be summarised as follows :—

1. *Preliminary tests for ammonium and the alkalis*—
   (*a*) *Ammonium.*—Part of the original substance is boiled with sodium hydroxide and the liberated ammonia tested with litmus paper.
   (*b*) *Sodium and Potassium.*—Part of the original substance is boiled with ammonium phosphate solution and filtered. The heavy metals remain on the filter as the phosphates and the filtrate containing sodium and potassium is divided into two parts. One part is tested for sodium, using nickel uranyl acetate ; the other is heated with excess sodium hydroxide solution to remove ammonium salts and tested with sodium cobaltinitrite.
2. *Group I.—Lead, Silver and Mercurous Mercury.*—After solution the group is precipitated with hydrochloric acid and the metals separated by the conventional procedure.
3. *Group II.—Lead, Calcium, Strontium and Barium*.*—These metals are precipitated with sodium sulphate in the presence of ethanol. Lead sulphate is extracted with ammonium acetate solution. The remaining sulphates are converted to carbonates by boiling with excess sodium carbonate. After filtering, the residual carbonates are dissolved in acetic acid. The alkaline earth metals are then separated, using one of the conventional procedures.
4. *Group III.—Arsenic, Antimony, Mercuric Mercury, Copper, Bismuth, and possibly Tin.*—The solution is carefully neutralised and then made slightly acid. Sodium thiosulphate is added and the solution warmed. The sulphides of the above metals are the final product of the reaction and are separated as follows :—

   Arsenic is separated by extraction with ammonium carbonate and the solution tested for its presence.

   Antimony and tin are separated by extraction with sodium carbonate, the filtrate divided into two parts each of which is tested for these metals using spot tests.

   Copper and bismuth are separated by extraction with nitric acid, leaving mercuric sulphide as the residue. The two former metals are separated, using ammonium hydroxide and confirmatory tests applied. The mercuric sulphide is dissolved in aqua regia, evaporated, neutralised, made slightly acid and a confirmatory test applied. Often tin is not precipitated under these conditions and in any case the precipitation is not complete. It will always be present, therefore, in the following group.
5. *Group IV.—Iron, Manganese, Chromium, Tin, Aluminium, Calcium, Lead and Phosphate.*—Phosphate, if present, is removed by the basic acetate method. The metals are precipitated by ammonium hydroxide and carbonate. The latter is necessary to precipitate calcium left in solution from the Group II separation. The precipitate is extracted with boiling sodium hydroxide solution and filtered. The filtrate contains lead, tin, aluminium and calcium. The solution is divided into four parts and tests for the individual metals applied to each part. The residue, containing iron, manganese and chromium, is dissolved in hydrochloric acid and divided into three parts, each of which is tested for these metals.
6. *Group V.—Nickel, Cobalt, Cadmium and Magnesium.*—The solution is boiled with sodium hydroxide solution to expel ammonia and precipitate the metals. The precipitate is dissolved in acetic acid and divided into four parts, each of which is tested for the metals under examination.
7. *Group VI.*—The only remaining metal is zinc, which is tested for in the filtrate from Group V.

Modification of the Original Scheme

The main essentials of the original scheme, namely, the group reagents, are retained throughout. Certain of the separations we describe are different from the original separations and a number of different confirmatory tests is used. We do not consider it necessary to indicate these variations in the present paper and those interested should compare our scheme with the original. We have chosen different specific tests in many cases, because in our experience they are superior to the original recommendation. In some cases they are merely a matter of personal choice. For example, Mee proves the presence of zinc in his last group by adding potassium ferrocyanide.* We prefer to add ammonium sulphide and, if a white precipitate is obtained, to dissolve it in acid and apply two confirmatory tests.

For the sake of convenience we have altered the numbering of Mee's scheme. In the conventional tables

* It is of interest to note that this method of precipitating lead and the alkaline earths immediately after Group I was first proposed by Browning and Blumenthal to eliminate the losses which occur of a considerable part of the alkaline earths during the normal scheme of analysis.[3] These losses are ascribed to precipitation as sulphates in the hydrogen sulphide group due to oxidation of the hydrogen sulphide, formation of the carbonates and interference from large amounts of ammonium salts present in solution when the alkaline earth group is normally reached. Browning and Blumenthal reduced the alkaline earth sulphates to sulphides by ignition with carbon in order to get re-solution of the metals.

3 Browning and Blumenthal. *Am. J. Sc.* [4], **32**, 246.

* In the original paper it merely states that potassium ferrocyanide should be added to the sodium hydroxide solution filtered from the previous group. Obviously the solution must be acidified first.

the alkali metals and ammonium are allotted a group, although there is no common group reagent, hence we have called the series of tests applied to the alkali metals and ammonium, Group I. The silver, lead and mercurous mercury group becomes Group II, and so on. Since it appears out of place to allot a group to a single metal we have included zinc in Group VI (our numbering).

It will be seen that in the original scheme more metals spread into different groups than in the conventional scheme. Lead spreads into three and calcium and tin into two groups. On the micro-scale we have found this spreading to be reduced considerably. Lead is confined to Groups II and III (our numbering) and calcium to Group III. This is probably because of the more efficient precipitation obtained in the modified scheme due to our using more ethanol†. In spite of careful neutralisation of the Group IV solution we have only occasionally precipitated tin in this group. It almost always confines itself to Group V. Hence, on the micro-scale, the carrying over of metals into later groups is considerably reduced. However, since careless manipulation may lead to further spreading, Mee's original arrangement, which allows for this, has been retained. If it is found, therefore, that, say, calcium does not appear in Group V, whilst it was present in Group III, this need cause no alarm, because it signifies that the previous separation was complete.

In the preliminary tests for the alkali metals in the original scheme it will be noted that the nickel uranyl acetate test is applied directly to a solution containing phosphate. We have always used zinc uranyl acetate for the sodium test and its use was retained in the present scheme for the sake of convenience. It is well known that this reagent cannot be used directly in the presence of phosphates, owing to precipitation of uranyl phosphate.[4] Such precipitates were found when applying this reagent following the original instructions even though sodium was absent. As is to be expected, phosphate also interferes with the nickel uranyl acetate test, according to Feldstein and Ward[5] (who were the first investigators to examine the reagent thoroughly, since Streng[6] first recommended this general type of reagent in 1886). Various methods have been used to remove phosphates, but most have the disadvantage of introducing excessive amounts of soluble salts in the test solution. The method found most suitable was the zinc carbonate method of Overman and Garrett,[7] which avoids this difficulty. On introducing this modification, satisfactory results were obtained for the sodium test.

The phosphate separation described by Mee is inapplicable if tin and phosphate should be present together, since stannic phosphate is insoluble in acetic acid. In any case we prefer the zirconium nitrate method[8]—probably the best phosphate separation ever devised—and have substituted it for the basic acetate method not only in this scheme, but in microanalytical schemes based on the conventional separation.

(To be continued)

† The precipitate obtained in this group should be examined carefully. If an excessive amount of ethanol is used sodium sulphate will precipitate. It is obviously readily distinguishable from the group precipitate in being soluble in water.

4 Kolthoff and Barber. *J.A.C.S.*, 1928, **50**, 1625
5 Feldstein and Ward. *Analyst*, 1931, **56**, 245.
6 Streng, *Z. Wissench. Mikroch.* 1886, **3**, 129.
7 Overman and Garrett. *Ind. Eng. Chem.* (An. Ed.), 1907, **9**, 32.
8 Friend, Vallance and Challis. *Nature*, 1940, **146** 63.

Apparatus in Quantitative Microanalysis

By R. Belcher and F. Burton

IV.—Apparatus used in Conjunction with Test Papers

FEIGL[1] has described an apparatus generally used for the identification of a particular gas in the presence of large amounts of other gases. It resembles the apparatus shown in Fig. 1 at E except that the stopper is more funnel-shaped and much wider at the top. The apparatus to be described is as effective and can be used for any reaction where the gas is identified by using test-paper. In both cases the paper is laid on top of the stopper.

A piece of glass tubing is drawn out to the shape shown in Fig. 1A. It is then cut and treated as described in a previous article[2] to give the shape shown in Fig. 1C. A piece of capillary tubing of wide bore is drawn out as shown in Fig. 1B, and cut at the points indicated, using a tiny flame from a capillary jet to form the stopper shown at 1D. The edges are ground smooth, using a paste of carborundum powder and water, and the stopper is finally ground into the tube to give a gas-tight joint as described previously.[2] The finished apparatus is shown in Fig. 1E.

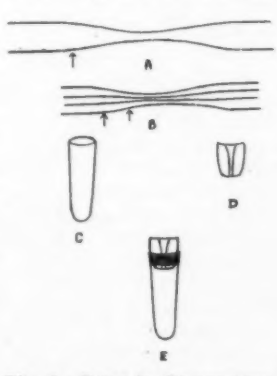


Fig. 1—Steps in the construction of the apparatus.

Fig. 2.—Alternative form of apparatus.

An alternative form which we prefer since it can be made more quickly and avoids any risk of the gas escaping round the edges of the paper is shown in Fig. 2. A disc of impregnated test-paper is placed over the mouth of the tube and clamped firmly in position by means of the glass collar. The latter is best cut from a drawn-out section of tubing using the flame from a capillary jet, and the edges then smoothed by rubbing on a glass plate with a paste of carborundum powder and water. In both these forms of apparatus the test is carried out as described in the article II_1 in this series.

1 F. Feigl. "Spot Tests." Nordemann Publishing Co. Inc., N.Y.
2 R. Belcher and F. Burton. METALLURGIA, 1945. **31**, 272.

Microchemical Methods

By Cecil L. Wilson

1. An Easily Constructed Filter

ALTHOUGH a centrifuge, which may be one of the small hand types, is undoubtedly the most suitable instrument to use for qualitative separations on the micro-scale, several alternatives are available or can readily be devised to meet those circumstances in which a centrifuge is not convenient.

A pipette of the form showed in Fig. 1 may be usefully employed. This is constructed from thick-walled capillary-bore (1–2 mm.) glass tubing, the tip being blocked by a small tuft of Gooch asbestos or cotton wool. With practice it is possible to control the pressure on the rubber teat very accurately, using only one hand, so that the correct rate of filtration is maintained. Too rapid filtration may, of course, result in penetration of the filter tuft by the precipitate.

After all the liquid is drawn into the bulb of the pipette, the precipitate is washed with a small amount of a suitable wash liquid. The pipette is turned sideways, so that all the liquid lies in the bulb, and air is expelled by pressure on the rubber teat. On once more raising the pipette to the vertical, the wash liquid may then be drawn in, washing any precipitate on the filter tuft in passing. The tuft, together with any adherent precipitate, is then withdrawn by fine-tipped forceps, and returned to the bulk of the precipitate for further treatment.

Fig. 1. Simple form of pipette.

A development of this type of filter is shown in Fig. 2. Here the filter is separable from the main pipette at a ground joint, and may be fitted either with an asbestos plug (Fig. 2b), or with a sintered glass mat (Fig. 2c). The pipette is constructed as before, and then another piece of tubing is softened at one end and slightly widened to approximately the same taper as the point of the pipette (Fig. 2d), using a metal point, such as the handle end of a small file. This modified capillary is brought just to softening and allowed to cool very slowly so as to anneal it thoroughly. It is then cut off (Fig. 2e) and, holding it in forceps, the hole at the cut end is either narrowed slightly by fire-polishing, or receives a mat of ground glass of suitable size, which is then sintered in position. The filter tip is subsequently ground on to the tapered point of the pipette with carborundum.

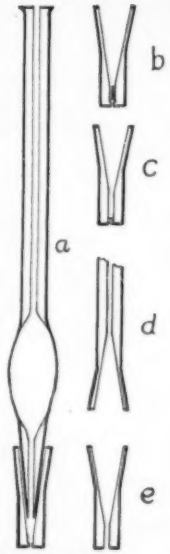


Fig. 2.—Construction of filter tip.

Several tips may be ground sufficiently accurately to be interchangeable on a single pipette. Each filter can then, in use, be returned to its appropriate precipitate, the same pipette being used throughout for a series of successive separations.

A Spot Reaction for Bismuth

IN a recent investigation, West and Tokos[1] have shown that when an aqueous brucine citrate solution (containing 100 g. citric acid, and 12 g. brucine in 100 mls. water) is added to a test solution, followed by potassium iodide, the presence of bismuth produces a yellow-orange precipitate, the colour of which changes, after about a minute, to an intense brick-red. As little as 0·3 mg. of bismuth may be detected at a limiting concentration of 1 : 100,000.

None of a very wide range of ions gives a similar precipitate, and the test is satisfactory in acid solution. Cadmium, mercury, copper, silver and lead reduce the sensitivity of the test, but a positive may still be obtained. The only common ion which masks the test (due to the formation of a black precipitate) is mercurous mercury.

In order to carry out the reaction, one drop of test solution is placed on a spot plate, followed by a drop of a boric acid solution (containing 30 g. boric acid and 20 g. sodium hydroxide per litre) and a drop of saturated aqueous sodium bisulphite solution. On final addition of a drop of 20% aqueous potassium iodide solution, the characteristic precipitate will form if the test drop contains bismuth. Yellow precipitates, due to the liberation of iodine and the formation of complexes, will not be confused with this.

Thiourea, proposed by a number of workers as a reagent for bismuth, is also here recommended as a highly selective reagent, although less sensitive than brucine citrate. The test solution on a spot tile is treated with a drop of N/10 nitric acid and a drop of aqueous 5% thiourea solution. A yellow colour indicates a positive test, with only antimony, among the commoner ions, reacting similarly. This test is masked by mercurous mercury, like the brucine citrate test, and, of course, by coloured ions. Thus, although the authors claim that both brucine citrate and thiourea are satisfactory without prior separation of the bismuth, it has been pointed out elsewhere[2] that copper, iron, nickel and cobalt should be removed before testing with thiourea. This presumably also applies to such ions as chromate, dichromate and permanganate.

[1] P. W. West and J. V. Tokos, *Ind. Eng. Chem., Anal. Ed.*, 1944, **16**, 761.
[2] *Organic Reagents for Metals*, 4th Ed., (Hopkins and Williams) 1943. Appendix.

Induction Furnace for Melting Aluminium

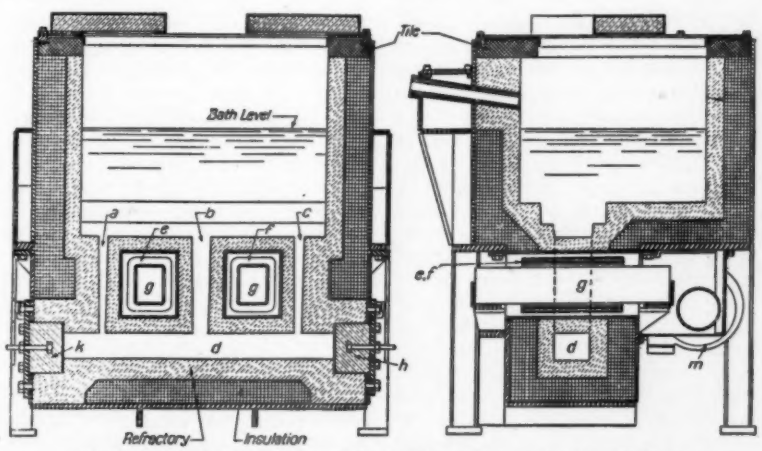
By Manuel Tama

ALTHOUGH the induction furnace was successfully adapted to the melting of brass about 1917, it was a long time before the submerged resistor type of furnace could be adapted to the commercial melting of aluminium and aluminium alloys. The difficulty lay chiefly in the low specific gravity of aluminium alloys. In the heavy metals, non-metallic particles contained in the melt are much lighter than the metal, so that they tend to rise to the surface of the bath. With the light metals the slag particles have about the same specific gravity or are heavier than the melt. Obviously, if non-metallic non-conductive particles are contained in the secondary loop of an induction furnace, they will tend to increase the resistance of the secondary and to change the character of the furnace. In addition, the slag particles tend to stick to the walls of the melting channels and gradually to decrease their cross section. Thus, when attempts were made to melt aluminium in the submerged resistor furnace designed for brass and other heavy metals, the resistor channels were clogged by non-metallic particles.

An induction furnace of the submerged resistor type in which aluminium alloys can be melted continuously, without fear of clogging the channels, is shown in Fig. 1. The secondary circuit consists of two or more straight vertical channels connected at the bottom by a horizontal channel of larger cross section. Depending upon the kind of metal charged into the furnace, there will be some deposits of slags in the channels chiefly in the vertical legs. However, these deposits can be easily scraped off from time to time by using tubular tools having the same cross section as the channels. The slag particles are scraped off and can in most cases be extracted from the surface of the metal.

The most widely used method of melting in aluminium-alloy foundries consists of a combination of melting and holding furnaces. The raw metal, in the form of pigs, scrap, risers, and gates, is charged into large melting furnaces. Molten alloy of the desired composition and temperature is tapped from the melting furnaces and transferred to holding units of smaller capacity and melting rate. This method has been considered necessary previously for the following reasons:

(1) The larger fuel-fired melting furnaces are more efficient than the smaller ones. Therefore, the over-all efficiency of the furnace installation was increased by the combination of the two types.



Principal vertical sections of induction furnace for aluminium.

(2) The close temperature range needed at the molds was easier to maintain with a small holding furnace of limited capacity.

(3) In some cases, where foundries prefer to prepare their own alloys, the alloying was performed in the large melting units, the molten metal of the required analysis was delivered to the melting units.

The trend of the aluminium industry seems to be towards supplying the foundries with alloy ingots of guaranteed analysis, either from virgin or secondary metal, and it appears that this will be the predominant practice in the post-war era. Under these circumstances the logical method of melting should consist of using furnaces which will enable the foundries to use only one furnace for melting and discharging, thus obviating the necessity of double melting and of transferring molten metal from one pot to the other. A furnace capable of being used in the manner just described should answer to the following requirements:

(*a*) Large melting capacity in small space.

(*b*) Close temperature control, while cold metal is charged and molten metal discharged continuously.

(*c*) Comfortable operating conditions with only small amounts of heat being radiated to the surroundings.

(*d*) Thorough mixing of the molten bath.

The standard frequency induction furnace of the submerged resistor type seems to answer to these requirements.

The gas pickup of aluminium alloys is one of the most difficult problems the aluminium melter has to confront. A vast amount of research has been carried on in this field. All investigators agree on certain principles which have crystallised into the following fundamentals:

(1) Most harmful is hydrogen and hydrogen dissociated from moisture contained in the atmosphere surrounding the bath.

(2) All the other gases are less harmful.

From *Mach. Eng.*, 1944, **66**, pp. 729–736.

(3) Gas pickup increases considerably when the temperature is raised.

The induction furnace is not the cure-all for avoiding gas pickup. However, users of induction furnaces have not reported any failures due to gas pickup in the melting stage, up to the present time. Hydrogen, of course, is not present in the gases covering the molten bath contained in an induction furnace. Moisture may be contained therein or may be brought in with the cold charges, especially on humid days, but the temperature existing above the metal bath is low. The induction furnace is decidedly a cold-top furnace. The highest temperature is found at the bottom of the furnace. Slightly lower temperatures are observed on the surface of the bath, and considerably lower temperatures are measured on top of it.

Most of the users of induction furnaces for foundries report that they are using no fluxes. One large rolling mill casting large billets for extrusion and forgings, reports that over a long period of time they have found only one half of the degassing agents to be necessary as compared with other furnaces. Further experience will have to reveal whether or not the induction furnace can be used as it is for standard melting without fear of gas pickup. It may be mentioned that the induction furnace has been the key to the development of commercial large-scale methods of producing oxygen-free and gas-free copper. The induction furnace, with its characteristic features of internal production of heat and of a totally enclosed metallic shell, offers unlimited possibilities to the use of controlled atmospheres under high and low pressures for melting of metals.

Flash Chrome Plating to Size

By C. L. Tanner

THERE are two types of chrome plating: that commonly referred to as decorative and the other known as hard plating. The former usually involves copper-plating, the base metal; nickel-plating over the copper; polishing the nickel to a mirror finish; and thin fluting a very thin film of chromium over the polished surface. Hard chrome plating involves electroplating a more substantial quantity of chromium directly on the base metal. Flash chromium plating is a form of the latter type and is applied to deposits up to 0·001 in. or less. Parts which are so plated are not ground after plating, although they are frequently lapped, honed, or buffed to provide the required finish. In any case, it is necessary to control the amount of deposit. This is accomplished through careful control of plating time, solution content, temperature, and current density. Tolerances equal to one-tenth of the plating thickness can be maintained.

Since any imperfection in the surface of the base metal is magnified in plating, it is necessary to exercise great care in the preparation of the surface before flash-plating. After being ground, wheel marks should be completely removed before plating. This is most often accomplished by buffing, but in cases where true cylindrical form must be maintained, lapping or honing is sometimes used.

From *Mech. Eng.*, **66**, 1944, p. 725.

The purposes for which flash chrome is now being used are either low friction or corrosion resistance, or both. Frequently flash chrome is used to accomplish one result, and it develops that some other benefit is derived. For instance, an oil-tool company manufactures a cone-shaped fitting which is used to install rubber drill-pipe protectors. In service these tools rusted and flash chrome was tried as a protection against corrosion. When put in service, the operator was amazed to discover that only a fraction of the customary pressure was required to force the rubber over the fitting. The result is that in addition to prolonging the life of the tool, its use has been made much less difficult and the breakage of rubber collars during assembly has been reduced 50%.

Originally hard chrome was used to salvage worn tools, such as taps, drills, reamers, and forming tools. This did not prove profitable owing to grinding costs. However, it did indicate that advantages could be gained through flash-plating. It is now common practice to flash-plate new tools or those which are slightly worn.

The principal advantage gained is through reduction of friction. Plated tools do not pick up metal being worked and chips tend to slide off the tool surface without transferring their heat to the tool. In one instance, the life of chasing cutters was increased 10 times, cutting $\frac{3}{4}$–20 threads in 4,130 steel; similar results have been obtained with other cutting tools.

Flash chrome has been used successfully in increasing the size of standard drills, taps, and reamers to produce holes or threads which are slightly larger than standard sizes. It is possible to increase diameters by as much as 0·002 and still maintain close tolerances. This has often saved the cost of special tools.

One of the important uses of flash chrome is in metal stamping. Through the reduction of friction, better parts are produced with less rejects. The life of dies is greatly increased since the chrome can be replaced before any steel has been removed from the die. Plastic and rubber molds frequently present problems due to the corrosive action of the material being molded or through adhesion. In most cases flash chrome avoids the difficulty and is widely used.

In the oil-tool industry flash chrome is finding favour for many purposes. One manufacturer uses this process on the threaded stems of gate valves to reduce friction and prevent corrosion. The cap screws used on the bonnets of large valves are flash-chrome-plated to facilitate their removal when repairs are necessary. Reciprocating-pump rods are plated to provide a better packing surface.

Flash chrome has not been used very extensively in hydraulic equipment for aircraft; however, there is no reason why it should not in many instances replace heavier deposits which require grinding. One problem in this connection would be to obtain a perfect finish on the base metal without developing flat spots in buffing. This could probably be accomplished with either superfinishing or centreless buffing. Centreless buffing would also be indicated after plating.

Hard chrome has been used on plug gauges for perhaps 10 years. More recently, flash chrome has been found to be just as effective. Where very close tolerances are encountered, the gauges are lapped after plating with good results. The life of thread gauges is indefinitely prolonged by grinding them to the low limit and plating to the high limit. When worn to the low limit they are replated.

There have been many important developments in the use of flash chrome on engine parts. Heavy deposits of chrome failed on camshaft lobes. Thicknesses of 0·001–0·0003 in. have been very successful. Crankshafts have been flash-plated with

good results as a means of reducing friction. There are two Continental truck engines in operation with cylinder walls plated to size. They have not been in service long enough to develop any definite results, but the engines are operating efficiently. Valve stems are flash-chrome-plated to reduce wear and eliminate sticking, and the surfaces under the heads have been successfully plated to prevent adherence of gummy deposits. An oil-producing company has had difficulty with carbon deposits in engine cylinder heads where casing-head gasoline is used. This condition has been corrected by flash-plating the heads.

There have, of course, been hundreds of other effective uses of flash-chrome plating. There have also been some failures. Like so many other developments of the last decade, chrome plating, and particularly flash chrome plating is in its infancy. However it is safe to conclude that flash chrome plating is worth a trial if it is desired to reduce friction, retard corrosion, or provide longer life for metal parts.

Age-Hardening Copper-Manganese-Nickel Alloys

By R. S. Dean, J. R. Long, T. R. Graham, and C. W. Matthews

AN investigation was carried out on copper-manganese-nickel alloys containing 22–24% of manganese and equal amounts of nickel. The alloys were prepared in high-frequency induction furnaces and cast at 1,350°–1,375° C. After forging and rolling at 700°–850° C., all heats were hot-worked into 0·4 in. plate, annealed at 650° C., quenched, cold-rolled to 0·2 in. thickness, annealed again and cold-rolled further to 0·08 in. thickness. Half of the material from each ingot was again annealed at 650° C., and the remainder was used in the cold-rolled condition. The composition and the physical properties of the alloys in sheet form as annealed and cold-worked are given in Table I.

As a result of a series of heat-treatment experiments, a temperature of 650° C. was used for solution treatment. The grain size of the alloys solution treated at this temperature ranged from 0·010–0·015 mm., compared with 0·12–0·15 mm. for alloys treated at 900° C. The effect of ageing time and temperature on alloy solution treated at 650° C. was determined by hardening at temperatures ranging from 350°–550° C. for time periods up to 24 hours, and satisfactory hardening was obtained in all three alloys. Cold-worked material hardened more rapidly than solution treated material, and alloy MN 24 hardened at the greatest rate and MN 20 at the slowest rate. At 475° C. satisfactory hardening was obtained on all alloys as cold-worked, but MN 20 did not harden beyond B 90 from the solution treated state. At 500° C. none of the alloys hardened from the soft state, and although they all responded from the cold-worked state, the hardness was slightly lower for MN 22 than MN 24 and considerably lower for MN 20. At 550° C. only the cold-worked MN 24 hardened and barely reached C 34.

From *American Society for Metals*, 1944, Preprint No. 11, pp. 1-22.

TABLE I.—COMPOSITION AND PROPERTIES OF COPPER-MANGANESE-NICKEL ALLOYS

Alloy	Composition			Condition	Proportional Limit Tons per sq. in.	Yield Strength Tons per sq. in.	Ultimate Strength Tons per sq. in.	Elon. %	Rockwell Hardness
	Cu.	Mn	N.						
MN 20	60	19·9	22·0	Annealed	14·3	16·5	37·5	39	B 74
MN 20				60% C.R.	40·2	55·4	56·7	3·2	C 23
MN 22	56·2	21·6	22·2	Annealed	12·1	17·2	38·9	40	B 77
MN 22				60% C.R.	40·2	56·9	59·6	3·0	C 24
MN 24	52·0	23·6	23·7	Annealed	14·3	19·0	40·2	40·2	B 79
MN 24				60% C.R.	37·1	59·4	60·7	3·0	C 26

From the data obtained it was concluded that after solution treatment, ageing at 350°–450° C. would produce satisfactory hardening, and that the rate of hardening was such as to permit control of the ageing time to obtain any desired hardness in the alloys from Rockwell C 30 to C 45. These results were used in subsequent work to predict the time required to produce a given hardness, and different lots of cold-worked alloys were hardened to within 2 points of the predicted value. Solution treated material, however, did not respond quite as well. To determine the effects of prolonged treatment at ageing temperatures, specimens of each alloy were aged for periods up to four weeks at 375° and 450° C. The results obtained showed that there was no tendency for over-ageing at 375° C., but that at higher temperatures a perceptible increase in hardness occurred at the end of the second week and this decrease was quite definite at the end of the fourth week. Micro-examination of the hardened alloys showed that two different types of structure were developed depending on the ageing temperature. When aged at temperatures up to and including 400° C., a finely divided precipitate appeared in the grain boundaries and spread gradually throughout the grains, while ageing at 450° C. and above produced a grain boundary phase which showed little tendency to spread through the grains.

More variation occurred in the physical properties of alloys hardened from the solution treated state than from alloys hardened from the cold-worked state. The tensile properties increased regularly with hardness for both conditions and at all three ageing temperatures. The maximum properties of 96, 90, and 76 tons per sq. in. for ultimate stress, yield stress and proportional limit respectively for alloy MN 22 were obtained with a hardness of C 45 at an ageing temperature of 450° C. A comparison made between the physical properties of all three alloys hardened from both conditions showed each alloy to respond in a similar manner to MN 22. Alloy MN 20, hardened from the solution treated state, had higher yield strengths and proportional limits and somewhat lower elongations than either MN 22 or MN 24 in similar conditions, but as MN 20 could not be hardened to quite the same level as the other two alloys, the optimum composition appeared to be between 22 and 24% each of manganese and nickel.

The physical properties of the alloys compare favourably with those of age-hardened copper-beryllium alloys containing 2–2·5% beryllium.

While most of the data was obtained on copper-manganese-nickel alloys made with electrolytic manganese, data was also obtained on several heats of the alloys made with commercial grades of manganese for comparison. It was found that these alloys were more difficult to fabricate and had lower elongations for any given tensile strength and hardness.

A Comparison of Platinum and Palladium Hydrogen-Electrodes in Aqueous Solutions of Acid Potassium Phthalate

By Walter J. Hamer and S. F. Acres

A STUDY was made of the reproducibility of hydrogen electrodes of various types and of silver-silver-chloride electrodes of the thermal-electrolytic type in aqueous solutions of phthalates, in order to learn whether phthalates are reduced to hexahydrophthalic acid and the electromotive force thereby changed. If so, glass electrodes would have to be used to determine the pH values of solutions of phthalates. This type of study is necessary for all reducible materials. Electromotive-force measurements of the electrode combinations were made for various periods of time. The potentials of hydrogen electrodes prepared with platinum sponge under a variety of conditions constantly increased with time and frequently were erratic, whereas those made with palladium sponge under different conditions remained remarkably constant for periods of 35 hours. Even after 75 hours, the potentials increased only 0·3 mv—which corresponds to an increase of only 0·005 in pH. Palladium or platinum electrodes having the same type of coating but of different ages agreed in potential after 2 hours in phthalate solutions. The rate and the magnitude of the increase in potential for the platinum electrodes after approximately 2 hours depend mainly upon the thickness of the metallic sponge. The characteristics of the metallic sponge, of the current density used in the electrolysis; of the concentration, composition acidity, and conductance of the plating solution; and of the concentration, composition, pH, and buffer capacity of the phthalate solutions in which the electrodes were used. The difference in the behaviour of platinum and palladium hydrogen-electrodes may be caused by their different catalytic activity.

Reliable measurements can be made with hydrogen electrodes in aqueous solutions of acid potassium phthalate and phthalate solutions of pH ranging from 2·73–5·33 and for temperatures from 0°–60° C.

The inconsistencies regarding the behaviour of hydrogen electrodes in phthalate solutions reported in the literature are due to the type of hydrogen electrode used and not to the design of the cell, or to variations in the potential of the liquid junction formed between the solutions of phthalates and the potassium chloride of the calomel electrode, or to the unstable state or unaged condition of the electrodes, or to increased reduction of the phthalates at the hydrogen electrode because of impurities.

It has been found that the potentials of hydrogen electrodes prepared with palladium sponge of various thicknesses remain constant for 35 hours and increase only 0·3 mv after more than 100 hours of operation. Their characteristics are independent of the current density used in the electrolysis; of the concentration, composition, pH, and conductivity of the plating solution; and of the concentration, composition, pH, and buffer capacity of the phthalate solutions in which they are used.

On the other hand, the potentials of hydrogen electrodes prepared with platinum sponge increase steadily with time, and the rate of increase depends upon the thickness of the sponge. Frequently, such electrodes exhibit erratic behaviour because of reduction of the phthalates at the electrode surface. Equilibrium values of the potential may be obtained at times if a very thin coat of platinum sponge is used and a large volume of solution is employed in the hydrogen-electrode compartment. However, the former condition cannot always be reproduced. The different behaviour of platinum and palladium hydrogen electrodes may be accounted for by the difference in their catalytic activity.

From *Journal of Research of the National Bureau of Standards*, U.S. Dept. of Commerce, Vol. 33, No. 2, August, 1944, pp. 87, 102–103.

Vanadium in Grey Iron Castings

By R. G. McElwee and T. E. Barlow

A FACTOR which has accelerated the use of vanadium in cast iron is that this element has been found of the greatest importance in combination with other alloying elements. The presentation of data, however, is complicated by the fact that combinations of vanadium with other alloying elements are so numerous, and that laboratory methods of determining properties such as wear resistance, heat resistance and heat shock resistance, are inadequate. Since one of the greatest benefits of vanadium is the control of these properties, it has been found necessary to rely very largely on service data which are more reliable but more difficult to obtain.

Vanadium is the most potent of the carbide stabilising alloying elements customarily used in cast iron, and the carbide formed is stable at elevated temperatures and is tough and resistant to thermal shock. This toughness and stability of the carbide formed, even when vanadium is added in small quantities, is largely responsible for the more important applications such as wear-resistant castings which, under service conditions, are subjected to high stress and/or elevated temperatures. Recent investigations on pearlitic cast irons indicate that vanadium promotes small uniform graphite flakes and extremely fine carbides and reduces segregation. If the cooling rate is such that the vanadium-bearing iron is pearlitic, the pearlite formed tends to be much finer than without the additions. In irons already fully pearlitic without vanadium, the effect of the addition is to produce sorbite and this structure is of particular value in applications in which stress and wear must be resisted to the utmost degree.

Reduction of mechanical properties usually observed in unalloyed irons at elevated temperatures up to 700° C., occurs more slowly in vanadium grey cast irons due to the improved resistance to structural change of the carbide. At temperatures above the transformation, 715° C., the effect of vanadium is also marked. In Table I are given the properties of a series of grey cast irons as cast and after 150 cycles of heating to 815° C. followed by cooling until black. Improved retention of strength after prolonged heating is observed in all the vanadium irons. Satisfactory results in high temperature applications are also obtained with these irons and recent service data indicate that molybdenum-vanadium and chromium-vanadium combinations may be even more satisfactory.

From *The Foundry*, 1944, Vol. 72, No. 12, pp. 88–89, 246, 248, 250, and 252.

TABLE I.—EFFECT OF REPEATED HEATING AND COOLING (150 CYCLES) ON PLAIN AND ALLOYED CAST IRONS

CHEMICAL COMPOSITION (ALLOYS EXCLUDED) 3·15% C., 1·8%Si., 0·60% Mn., 0·12% S., 0·14% P.

Alloying Elements				Original Tensile Strength Tons per sq. in.	Final Tensile Strength Tons per sq. in.	Increase in Weight %	Warpage in. rise in 12 in.	Increase in Length %
Cu	Ti	Zr	V					
—	—	—	—	18·75	5·95–10·7	3·20	0·23	5·37
—	—	—	0·10	20·75	8·1–15·55	3·80	0·24	4·35
—	—	0·20	—	16·25	4·65–9·3	3·75	0·28	6·12
—	—	0·20	0·1	17·0	8·2–12·75	3·13	0·235	4·85
1·5	—	—	0·1	20·25	13·7–17·35	3·12	0·15	4·55
—	0·20	—	0·1*	18·75	6·0–15·25	3·85	0·25	4·92

While the addition of vanadium to grey cast iron effects an increase in tensile strength, transverse strength and Brinell hardness depending upon the amount added, composition of the base iron and the controlling cooling rate of the casting, vanadium as the only alloying element does not produce such increases alone as to warrant its use. When used, however, in combination with elements such as chromium, molybdenum, copper and nickel, the effect becomes sufficiently marked to make it a very economical and practical alloying element in grey cast iron. As regards chilling, in amounts up to 0·10–0·12%, the chill depth remains constant or may be reduced while in higher amounts the chill depth is increased unless compensated for by a powerful graphitising inoculant such as copper or nickel.

One of the most interesting combinations of alloying elements in grey cast iron is that of molybdenum and vanadium. Correct proportions of these elements impart high tensile strength, maximum impact resistance and relatively low Brinell hardness with a corresponding optimum machinability. A commercial electric furnace iron, containing 3·0% total carbon, 2·08% silicon, 0·58% manganese, 0·65% molybdenum, 0·10% vanadium and 1·0% nickel had a tensile strength of 30 tons per sq. in., a transverse strength of 3,740 lb. on 18 in. centres, a Brinell hardness of 248, and a Charpy impact of 66 ft. lb. High carbon molybdenum-vanadium cast irons containing 3·7–3·9% carbon, 0·8–1·4% silicon, 0·75–1·25% molybdenum and 0·2–0·3% vanadium have been developed for applications which require exceptional wear resistance and resistance to heat cracking, and in which metal sections involved permit the use of material having a tensile strength of 17 to 22 tons per sq. in. Combinations of molybdenum, vanadium, chromium and nickel are also used in quenched and tempered grey cast irons in which maximum toughness and tensile strength in the Brinell hardness range 400–500 if desired.

Strain Ageing of Killed Low-Carbon Steel

with Particular Reference to the Effect of Titanium

By G. F. Comstock

THE strain ageing of heat-treated specimens cut from forged bars of killed low-carbon steel melted in a small induction furnace was studied by six methods, including comparison of the yield point, and noting the change in impact value, hardness and damping capacity on ageing after straining. The steels tested ranged in composition from 0·022–0·135% carbon, 0·16–0·56% manganese, 0·002–0·23% silicon, 0·0033–0·0196% nitrogen, and up to 0·705% titanium. Manganese and silicon were added to all the heats after melting, so that all the steel was killed and the ingots were sound. Aluminium up to 0·15% was also added to many of the heats, and when high nitrogen was desired, about 0·2% was added, after deoxidation in the form of sodium cyanide. Titanium was added in the form of 40% low carbon ferro-titanium containing about 7% aluminium. Heat-treatment consisted in normalising at 900°–920° C. followed by cooling in still air, and annealing at 620°–635° C. for six hours followed by slow cooling in the furnace.

The results obtained showed that strain ageing shown by the return of a definite yield point in a specimen strained in tension is entirely different from strain ageing shown by loss of notched-bar impact value in strained specimens held for appreciable periods of time. Steels classed as "ageing" by the yield point method were usually classed as "non-ageing" by the impact method, and steel classed as "non-ageing" by the yield point method may show comparatively low impact values. Whether a given steel shows "strain-ageing" especially by the impact test method, depends often on the amount of strain, and 2% strain either in tension or cold drawing is generally insufficient. Damping capacity tests may be used to indicate susceptibility to the same kind of strain ageing as is shown by the yield point method.

Strong deoxidation as with aluminium decreased the amount of strain ageing of the kind shown by the yield point method in annealed steels with 0·08% carbon aged at room temperature but otherwise was ineffective for preventing that type of strain ageing. It did, however, decrease effectively the kind of strain ageing shown by impact tests, which is probably due to oxygen in the steel. The nitrogen of killed low-carbon steels, up to 0·015% soluble or 0·02% total, did not affect to any important degree the susceptibility to either kind of strain ageing.

Steels containing as much as 0·10–0·12% carbon with less than 4·5 times as much titanium, showed ageing by the yield point method when aged at 200° C. or 232° C., but did not show definite ageing in three weeks at room temperature. Steels of this type were non-ageing by the impact test method. Low-carbon steels containing at least 4·5 times as much titanium as carbon did not show a definite yield point after straining and ageing whether aged three weeks at room temperature, 16 hours at 200° C. or 1 hour at 232° C. Increase of yield strength on ageing after 5% strain was negligible in those steels. Low-carbon steels with less titanium, even though deoxidised with aluminium, showed strain ageing by the yield point method. The high-titanium non-ageing low carbon steels were coarser-grained than the others and some of them had just as good notched-bar impact resistance as the finer-grained lower-titanium steels.

In steels containing up to 0·135% carbon, the presence of titanium to the extent of at least 4·5 times the carbon content, greatly lowered the yield strength of the normalised steel, decreased the tensile strength to a smaller degree, increased the ductility, and caused the steel not to show a well-marked yield point. Such steels when heated for a long time at high temperatures and tested without subsequent heat-treatment at lower temperatures, gave yield and tensile strengths higher and ductilities lower than before such treatment or even after normalising.

From *Proc. Amer. Society of Testing Materials*, 1943, Vol. 43, pp. 521–541.

Flake and Shatter Cracks in Steels

By R. H. Harris

THE above defects have been more or less common in steels for some years and the subject has been investigated by numerous authorities. Large steel forgings often give irregular results in transverse tensile tests and the fractured surfaces show the presence of flaws, which are known as "flakes." Prior to 1914 this defect was not regarded as very serious in ordinary carbon steels, but with the greater use of high-class alloy steels, such as nickel and nickel chromium, it came into more prominence and particularly so when the defect was found in steels used for ordnance and war weapons. Since then considerable attention has been devoted to finding the cause of flakes. Numerous authorities have more or less agreed that they are due to hydrogen in the steel and extensive experiments have been carried out to find how and why hydrogen exists in steel.

The main conclusion seems to be that hydrogen is absorbed into the molten metal in the furnace and gets into the melt through the medium of moisture in the scrap metal, in the ore and in the burnt lime. Other authorities have given it as their opinion that moisture in the air is one of the main contributing factors of the hydrogen getting into the molten steel.

It has been stated that gases which are not liberated during solidification are retained in solid solution. This results in the formation of small silvery cracks or flakes in the interior of steel ingots and large forgings and particularly in nickel chromium steels. Shatter cracks have been found to be related to these flakes and it has been proved that the presence of hydrogen favours the development of flakes. Segregations and slag inclusions also increase the tendency to form flakes. But these flakes can be overcome by a slow cooling rate in the heat-treatment of the metal when hydrogen is evolved—i.e., at the surprisingly low temperature of 200–400° F.

Other authorities tell us that the moisture carried into a 1,000-ton blast furnace with the blast varies from 72 gallons per hour in the winter to 1,100 gallons per hour in the summer, and they therefore recommend that the air should be thoroughly dried before using, both in the blast furnaces and also in the open-hearth furnaces.

Another authority states that a great deal of water is contained in rust and thereby hydrogen may be introduced to the steel in the melt through the additions of scrap and mill scale. This authority calculates that 1% of rust to a 10-ton bath of steel introduces 900 cu. ft. of hydrogen measured under standard conditions. This quantity of hydrogen is twenty times the volume of the steel.

In Russia one authority has stated that a certain class of steel containing nickel and chromium and high carbon content was made in an 8-ton and a 15-ton basic electric furnace. One-fifth of the melts was made from scrap only, and the remaining from pig-iron and ore. The steel from the scrap melt showed flaking to the extent of 26·2%, whereas the steel made from the pig iron and ore melt showed only 18·6% of flakes. It is known that molten steel absorbs a thousand times more hydrogen than cold steel and, therefore, it would seem that the utmost care in the practice of melting is of the greatest importance. It is also a significant fact that steel made by the basic process both open-hearth and basic electric, is more prone to flaked steel than steels made by other methods.

It is well known that in bars the flakes appear as cavities like big open cracks, usually in series of individual cavities and not a continuous cavity in one or two places only. These cavities will always be found anywhere from 1 in. or more (according to the diameter of the bar) from the surface, and hardly ever found in the centre of the bar. It is easy to distinguish the difference between flakes and other internal defects in steel, such as piping segregations, roaks and silica lines. In flakes, the cavities are always found to be clean, bright metal without any impurities or foreign matter, whereas other defects as mentioned such as piping, etc., will be found to contain dirt and impurities, such as manganese sulphides, etc. Segregations are generally found to consist of foreign impurities, usually of a metallic nature, whereas roaks and silica lines are classed as containing some small portion of non-metallic matter such as silica powder, which has come through with the molten metal from the furnace.

Flakes occur chiefly in alloy steels, and also high-carbon steels, and where flakes are known to exist in these steels, they can be removed by suitable heat-treatment and slow cooling. When bars are found to contain flakes, the defect can be removed by forging down to a smaller dimension, provided that the steel is heated up well over the Ac_3 range and quick forging either in the hydraulic press or by hammer work is carried out expeditiously. Such treatment may necessitate the steel being re-heated two or three times in order to complete the forging to the reduced size, but under no circumstances should the hot working be continued below the range stated.

Another defect due entirely to flaking, only in a different manner, is to be found in steel rails, usually in the head or top of the rail, but here the flaking takes a somewhat different form to that in forgings and castings, and such defects in rails are attributed to cooling the rails too quickly and preventing the escape of hydrogen in the steel.

It is claimed that the process of sorbitic treatment of rails invented and patented by the late N. P. P. Sandberg materially assists in removing hydrogen from the internal sections, and this treatment also greatly improves the toughness and wearing qualities of the rails. In fact, the Sandberg process is now more or less in general use in the final heat-treatment of rails, and is also standardised.

From *Jour. So. African Inst. Eng.*, 43, No. 2, 1944, pp. 47–50.

Interferometer Measurements on the Expansion of Iron

By James B. Saunders.

THE interferometer has been applied by many investigators to the measurement of thermal expansion but has failed to yield the precision that they apparently expected and sometimes have claimed. In their explanation of the resultant discrepancies, most observers have attributed them to actual differences in the physical properties of the sample; however, some have admitted failure to find a satisfactory explanation.

Several sets of data, taken on relatively pure iron by different observers and different procedures, are compared. The results show good agreement between data taken with those interferometer methods that are free from tilting of spacers and air-film errors, whereas the failure to

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eliminate these two errors produces data that cannot be duplicated except by chance. The interferometer data that are free from these errors also agree satisfactorily with data that have been obtained by other precision methods.

Some investigators claim to have found indications of a characteristic temperature effect in the expansivity curve of iron in the temperature range from 0°–250° C. It is shown that when the expansion data are free from errors of tilting and changes in air films, the indications of such effects do not appear.

According to the results obtained, impurities do not affect materially the expansivity of iron in the range from room temperature to 400° C. as long as the carbon content is less than 0·05% and the total of the usual impurities does not exceed 0·3%.

In these precise measurements there are no appreciable irregularities in the temperature range from room temperature to 400° C.

The precision of the interferometer method has been greatly increased by making observations at a point directly over the contacts between the interferometer plate and a stable spacer.

Effect of As and Bi on the Mechanical Properties of Cu-Ni-P Alloys

By Clement Blazen, M.Sc., M.Agr.Sc., A.A.C.I.

THE investigation was planned to determine: (1) The precipitation-hardening properties of the copper-nickel-phosphorus alloys; and (2) The influence of arsenic and bismuth, singly and together, on the mechanical properties of these alloys.

It was carried out in conjunction with an investigation, previously published in these Proceedings,[1] on "The Influence of Various Elements on the Mechanical Properties of Copper containing a small percentage of Bismuth," and also formed part of a study of the influence of bismuth, nickel and phosphorus on the properties of commercial arsenical-copper.

The first part of the present investigation, arose out of a discovery some years ago of precipitation-hardening in phosphorus-deoxidised copper-nickel boiler tubes, containing approximately 2% nickel and 0·03% phosphorus, supplied to an Australian Railways Department. At that time there was little information available on precipitation-hardening in copper-rich copper-nickel-phosphorus alloys, but at the end of 1935 a short paper on the subject was published by E. C. Rollason and T. G. Bamford[2] and at the beginning of 1940 a comprehensive account was published by D. K. Crampton, H. L. Burghoff and J. T. Stacy.[3] Although the investigation carried out independently by the present author was not as comprehensive as that of Crampton, Burghoff and Stacy, the results are in agreement with those of the American as well as of the British authors; hence, only a summary of this aspect of the work is needed here to establish a basis for a study of the influence of bismuth and arsenic.

Sixteen copper-nickel-phosphorus alloys containing up to 2.7% Ni and 0·18% P, and seven copper-arsenic-nickel-phosphorus alloys containing up to 2·12% Ni, 0·18% P, and about 0·3% As were examined for precipitation-hardening properties. A brinell hardness of 105, a tensile strength of 26 tons per sq. in., an elongation of 25% on 2 in., and a reverse 90° bend number of 11 was the best combination of properties in the heat-treated alloys, such properties being obtained in an alloy containing about 1% Ni and 0·16% P. The influence of arsenic on mechanical properties was slight.

Thirteen copper-nickel-phosphorus-bismuth alloys containing up to 1% Ni, 0·17% P, and 0·022% Bi, and nineteen copper-arsenic-nickel-phosphorus-bismuth alloys containing up to 1·05% Ni, 0·20% P, 0·026% Bi, and about 0·4% As were also examined for precipitation-hardening properties and susceptibility to bismuth brittleness, with the following results:

(*a*) On the whole, the degree of precipitation-hardening was of the same order of magnitude as for the copper-nickel-phosphorus and copper-arsenic-nickel-phosphorus alloys, but in some alloys the bismuth appeared to reduce the extent of the precipitation-hardening.

(*b*) Brittleness did not appear in alloys containing phosphorus appreciably in excess of the quantity required to unite with all the nickel, but it appeared in a severe form resembling that found in copper-bismuth alloys when phosphorus was relatively low (0·12% and under), and nickel relatively high (0·9–1%), and also in a severe but modified form when both nickel and phosphorus were relatively high (above 0·15% P and 0·8–1% Ni), and the bismuth relatively high (above 0·005%). In general, alloys of intermediate composition (up to 0·12% P. and 0·2–0·7% Nil) showed signs of brittleness when phosphorus was near the lower limit and bismuth was relatively high (0·005% and over), but the results in this region of composition were rather inconsistent.

(*c*) Brittleness in alloys relatively high in both nickel and phosphorus differed from that in alloys relatively high in nickel and low in phosphorus in not being strongly developed by slow cooling from 825° C. or by reheating 10 hours at 600° C. after quenching from 825° C. In these alloys brittleness, when present, was strongly developed in the bend test and tensile fractures of precipitation-hardened samples without being much in evidence in tensile strength.

(*d*) There was no clear relationship between percentage of nickel phosphide and susceptibility to brittleness, but there was a relationship between susceptibility and excess phosphorus over and above that required theoretically to unite with all the nickel present. The percentage of excess phosphorus required to neutralise the embrittling effect of bismuth was less than the percentage of phosphorus required to neutralise the embrittling effect of bismuth in copper-phosphorus-bismuth alloys—e.g., 0·05% excess phosphorus neutralised the embrittling effect of 0·005% bismuth and 0·08% neutralised the embrittling effect of up to 0·02% bismuth. It is possible that the presence of nickel phosphide was a contributory factor in this respect.

Five copper-cadmium-arsenic-nickel-phosphorus-bismuth alloys were examined. The influence of cadmium appeared to depend on nickel and phosphorus as well as on bismuth contents; in general, cadmium appeared to exert a beneficial influence on susceptibility to brittleness.

Five copper-cadmium-arsenic-nickel-iron-phosphorus-bismuth alloys were examined. Brittleness was in evidence, although not ina strongly marked form, in an alloy containing 0·017% Bi.

The tensile strength of precipitation-hardened samples was not appreciably affected by the presence of cadmium and iron.

From *Proc. Austr. I.M.M.*, New Series, No. 135, 1944.

[1] C. Blazey, *Proc. Austr. I.M.M.*, New Series, No. 125, 1942.

[2] E. C. Rollason and T. G. Bamford, *Metals and Alloys* (1935), **6**, 345.

[3] D. K. Crampton, H. L. Burghoff and J. T. Stacy, *Trans. A.I.M.E.*, 1940, **137**, 354.

Aluminium Bronze Extrusions

By F. J. Miller

ALUMINIUM bronzes have been used for many years in cast form, but have not been widely available as forgings, rolled or extruded engineering materials. Such production as there has been has been largely confined to bronzes with low aluminium content which lack the more desirable attributes of hardness and tensile properties found in those aluminium bronzes having higher aluminium and iron contents. The demands of recent years have given great impetus to the use of extruded aluminium bronze by the aircraft industries, and the extrusion process has further increased physical properties to such an extent that aluminium bronzes are now in wide use in those applications where high strength, hardness, wearing and bearing properties are required.

The aluminium bronzes which respond well to fabrication by extrusion contain 2·5–5% iron and 8·5–15·0% aluminium. Aluminium bronzes of a modified type containing up to 6% nickel have also been used in applications requiring high tensile and yield strengths, with Brinell hardness of approximately 200 and elongations from 3–10%. A press having a capacity of 2,275 tons total pressure on the main ram and equipped for tube extrusion, with piercer attachment of 275 tons, has been found adequate for the successful fabrication of such alloys.

A press of the type mentioned consists of a ram, a container having an opening at each end and into which the hot billet is placed, a die and holder which has a tapered fit so as to be self-aligning when seated into one end of the container, a gate lock which holds the die and die holder firmly against the pressure attained in extrusion, a ram for exerting the pressure against the rear face of the billet and a shear for severing the butt or unextruded portion of the billet, at the face of the die, which, with its holder, is retractable from the container. The piercing attachment consists of a mandrel and holder actuated horizontally and centrally through a hollow ram.

In extrusion, billets are trimmed to length, rigidly inspected as to surface condition, internal piping or oxidation shrinkage and passed along a gravity conveyer into an oil-fired furnace having preheating, heating and holding temperature zones. Extrusion is carried out at as low a temperature as possible consistent with maximum pressure capacity. High billet temperature results in excessive grain size as well as surface defects such as blisters, shearing, etc. After the extruded product has cooled sufficiently to enable ease of handling, it is subjected to a very rigid inspection including what is known as a neck and break test and which consists of fracturing the rear portion of the bar whereby faulty grain size and other defects common to extrusion are exposed. When satisfactory results are obtained, the product is given a full annealing by passing through a continuous type gas-fired furnace with controlled cooling at the exit end. After annealing subsequent operations depend on the quality of production desired.

The comparison of sand cast aluminium bronzes with extruded aluminium bronzes are given in Table I, and show the advantages of the latter as far as physical properties are concerned.

Approximate Composition	2·75% Fe 8·5 % Al Balance Cu		3·25% Fe. 9·5 % Al Balance Cu		3·50% Fe 10·75% Al Balance Cu	
Form	Sand Cast	Extru.	Sand Cast	Extru,	Sand Cast	Extru.
Tensile strength Tons per sq. in.	37·5	41·0	39·0	44·0	45·0	47·5
Yield Strength Tons per sq. in.	14·0	18·75	14·75	20·0	18·5	23·5
Elongation % on 2-in.	40	25	20	20	14	12
Reduction of area %	40	20	20	18	12	10
Brinell hardness (3,000 Kg.)....	126	140	137	155	174	195

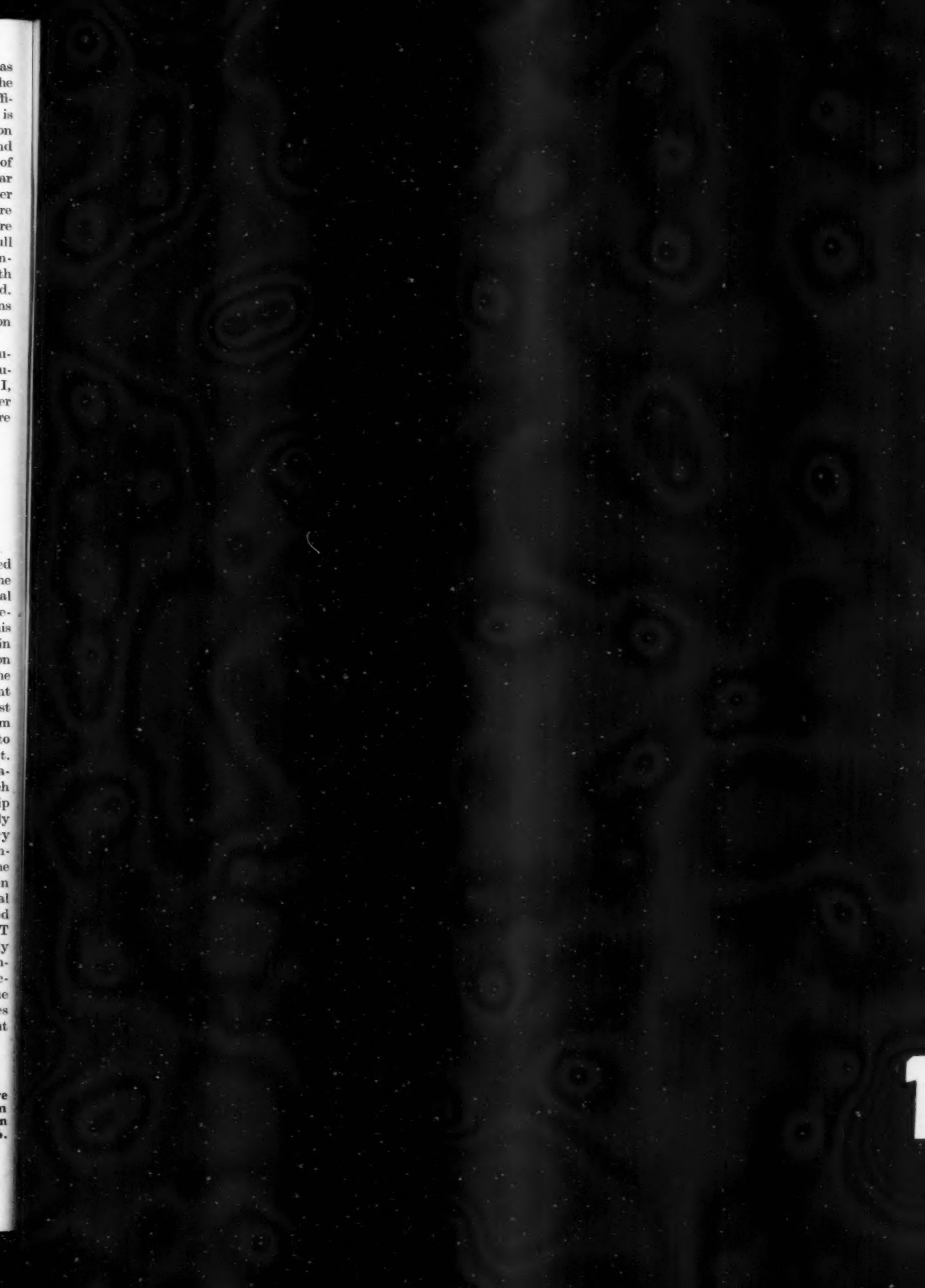
From *Metals and Alloys*, 1944, Vol. 20, No. 6, pp. 1598–1603.

Rigidized Steet Metal Lightens Panel Design

By D. E. Olshevsky

UNDER the trade name "Rigidized Metal," the Rigid Tex Corporation has developed embossed sheets with substantially greater rigidity in all directions. These sheets are produced from flat sheets by rolling in a pattern that is identical on both sides of the sheet and so designed as to have the effect of corrugations in two perpendicular directions. The tops of the protuberances or embossings are made flat in order to facilitate drilling, riveting, spot welding and other shop operations. The use of Rigidized sheet materials is most advantageous when the stressed panels are subjected to compressive, shear and diaphragm loads. In many instances a composite construction using a rigidized sheet and one or two plain sheets held face-to-face by spot welding or riveting is used. Curved panels can be made by bending plain sheets in face-to-face contact with the rigidized sheet and then holding the two sheets together in a jig for drilling and riveting. Rigidized sheets are now available in all ferrous and non-ferrous alloys in widths up to 36 in. and in any length. Gauges range from 0·005–0·125 in. thickness. The over-all depth of these sheets as measured from the tops of the embossings may be as much as $\frac{5}{16}$ in. Neither proportional limit nor ulitmate tensile strength are decreased by the rigidizing process. On the contrary there is usually a beneficial secondary work hardening effect resulting from plastic deformation. This effect is particularly pronounced in steels. An important consideration with respect to flexural rigidity is the differences in properties in different directions across the sheet. In most instances the maximum and minimum rigidity values are at right angles to each other, as in corrugated sheet. For close approximation, determination of critical stress values in such panels involves the two principal strip flexural rigidities that are normally applied and a knowledge of elementary torsional strip rigidities, which contribute approximately one-third of the total strain energy of the panel in virtual buckling. The average flexural improvement factor for a rigidized sheet of a pattern in 0·040 in. 24S-T aluminium alloy, is approximately 1·60, and the average torsional improvement factor is 2·11. The effective rigidity improvement factor of the rigidized panel is 1·78. This indicates a net improvement of 78% without weight increase.

From *Product Eng.* (U.S.A.), XV, November, 1944, No. 11, pp. 741–744).
Abstract Bull., XVI, January, 1945, No. 1, pp. 6–8

STEELS IN ENEMY AIRCRAFT.

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